LEVEL III

MINUTES
OF THE NINETEENTH
EXPLOSIVES SAFETY SEMINAR

VOLUME II

BILTMORE HOTEL
LOS ANGELES, CA

9 - 10 - 11 SEPTEMBER 1980

SPONSORED BY
DEPARTMENT OF DEFENSE EXPLOSIVES SAFETY BOARD
ALEXANDRIA, VA

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MINUTES OF THE

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ORGANIC SOLVENT
WASHOUT/RECLAMATION TECHNOLOGY

REPORT PRESENTED AT
DoD EXPLOSIVES SAFETY SEMINAR

BY

SOLIM S.W. KWAK
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INTRODUCTION

Bombs, projectiles, mines, and other munitions are loaded with binary explosives to enhance the explosive characteristics, chemical/thermal stabilities, and shelf life of munitions.

Currently, there exists a large tonnage of obsolete/unserviceable binary explosives loaded munitions for demil and disposal.

The traditional methods employed by the United States Military for the demil and disposal of explosives were:

(1) Burial in the ocean

(2) Burning and/or detonating in the open air

(3) Controlled burning of small munitions in deactivation furnaces

(4) Using a hot water/steam washout system followed by disposal of dried explosives.

The Ammunition Equipment Office, TEAD, Tooele, Utah have been studying an alternative washout technique to washout and recover the explosive components from one of the binary explosives, comp B.

Designated potential demil inventory of Comp B loaded 3.5 inch rocket is shown in Table 1.

The chemical composition of comp B consists of 60% RDX, 39% TNT, and 1% wax.

TABLE 1

POTENTIAL DEMIL INVENTORY OF COMP B

3.5 Inch Rocket	7,465,100 pounds (3,929,000 ea)

SOURCE: JCAP DEMILITARIZATION/DISPOSAL HANDBOOK

Our goal was to develop an organic solvent washout technique that required (1) a low washout temperature, (2) a low operation pressure, (3) a single washout and separation process.

Technical Discussion

Organic solvent washout/reclamation technology utilizes three mutually beneficial physical/chemical principles; these are (1) the solvation action of a warm solvent, (2) the high pressure mining action of liquid, and (3) the selective solubility of an organic solvent.

The solvation action of the warm organic solvent augments the high pressure mining action of the solvent, resulting in a very rapid washout of binary explosive from its casing. Then, the selective solubility effect of the organic solvent will effect the separation of the binary explosive into separate components, resulting in immediate and effective recovery of the soluble and the insoluble species.

To be suitable and effective, the candidate solvent should meet the following requirements: (1) it has a relatively high boiling point, (2) it has a low vapor pressure, (3) it has a good solvation property toward one of the explosive components, (4) it has a well defined selective solubility on the explosive components, and finally (5) it is thermally and chemically stable with the explosive components being washed out and most important it will not present a toxic hazard to the operators.

Thus, among the organic solvents investigated and considered, toluene was selected as a candidate solvent for the washout/recovery of explosive components from comp B.

The solubility data of RDX and TNT in toluene is shown in Table 2. For comparison, their solubility in benzene is also included.

TABLE 2

SOLUBILITY OF TNT AND RDX IN BENZENE AND TOLUENE

Solvent	Solubility in 100 gm of Solvent		
	Temp.	20°C	50°C
Benzene	TNT	67 gm	284 gm
	RDX	0.045(0.067%) gm	0.0115(0.04%) gm
Toluene	TNT	55 gm	208 gm
	RDX	0.02(0.36%) gm	0.085(0.04%) gm

From this data, the following assumptions are made.

(1) During the washout cycle, 208 pounds of TNT would dissolve in 100 pounds of toluene at a solvent temperature of 50°C, however, only 55 pounds of TNT would dissolve in 100 pounds of toluene at 20°C. The RDX is virtually insoluble in toluene at these temperatures.

(2) During the recovery cycle, the insoluble RDX will settle in the bottom of the washout tank and be recovered. This RDX can be washed with fresh solvent to remove any residual TNT or wax.

(3) In the cooling cycle, TNT rich solvent is cooled from 50°C to 20°C. TNT would precipitates from the super saturated solvent and can be recovered.

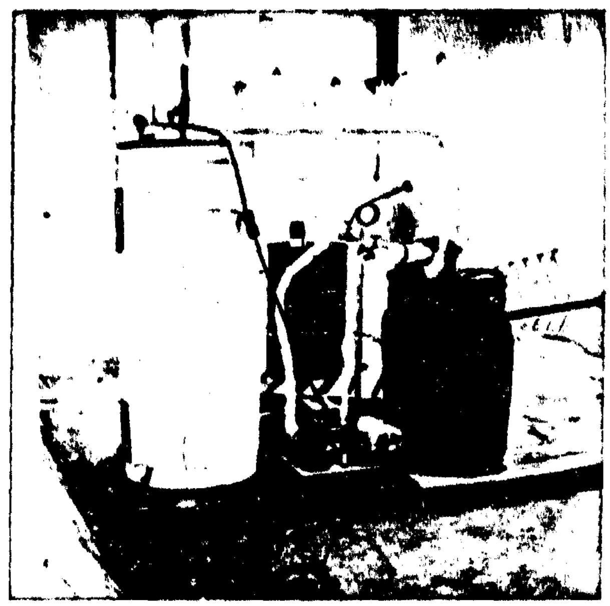
Description of Test Apparatus and Experimental Procedures

Figure 1 shows the apparatus constructed by the Ammunition Equipment Office to conduct the washout tests. The test unit is primarily consisted of (1) a washout tank, (2) a settlind tank, (3) an organic solven resevoir and heating tank, (4) a water heater, (5) a projectile holder/nozzle assembly, and (6) two pneumatic diaphram pumps.

Electrical heating elements were used to heat water to the temperature of 75°C. An air-driven diaphram pump forced this hot water through the heat exchanger coils submerged in the toluene.

The toluene in the solvent resevoir tank was heated to 50°C and maintained at this temperature by an automatic temperature controller, which adjusted the circulation of the hot water through the heat exchanger coils.

The munition to be washed was placed in the holder, centered above the nozzle. When the solvent temperature approached 50°C, the air driven solvent



pump was actuated. The pressure of solvent in the line to the nozzle fluctuated between zero to 40 psig as the pump cycled. Hot toluene was jetted into the munition cavity, rapidly washing the comp B out into the washout tank.

The soluble TNT was quickly dissolved into the warm toluene, and remained in the solvent as a solute. This TNT rich solvent flowed through the settling tank to the solvent resevior tank where the solvent was again heated to be recycled. Most of the settling of the insoluble RDX was accomplished in the washout tank before the solvent overflowed into the settling tank where the remainder of the RDX settled out.

After three minutes of washing, the solvent pump was turned off and the munition was removed and visually inspected. This process was repeated until the comp B was washed from the munition.

Test Results

Two types of comp B loaded munitions were washed out during the initial testings. The 105mm projectiles, each containing about 5 pounds of explosive, were completely washed out in 12 minutes. Approximately 80% of comp B was washed out in the first 6 minutes. Figure 2 shows, the reason the washing out of the remaining explosive took an additional 6 minutes was that the nozzle did not direct the flow of solvent with full force into all areas of the cavity. Only the solvation effect was available to remove the rind comp B.

It required 9 minutes to washout a 3.5 inch rocket. Approximately 70% of comp B was washed out in the first 3 minutes. The shape of the cavity made quick removal of the explosive difficult. Again, the lack of a correct matching configuration is the reason for the long washout time. The objective of these tests did not include optimization of nozzle designs. This work is planned for accomplishment in future tests.

WASHOUT RESULT

(105mm Projectile after 6 minutes of washing)

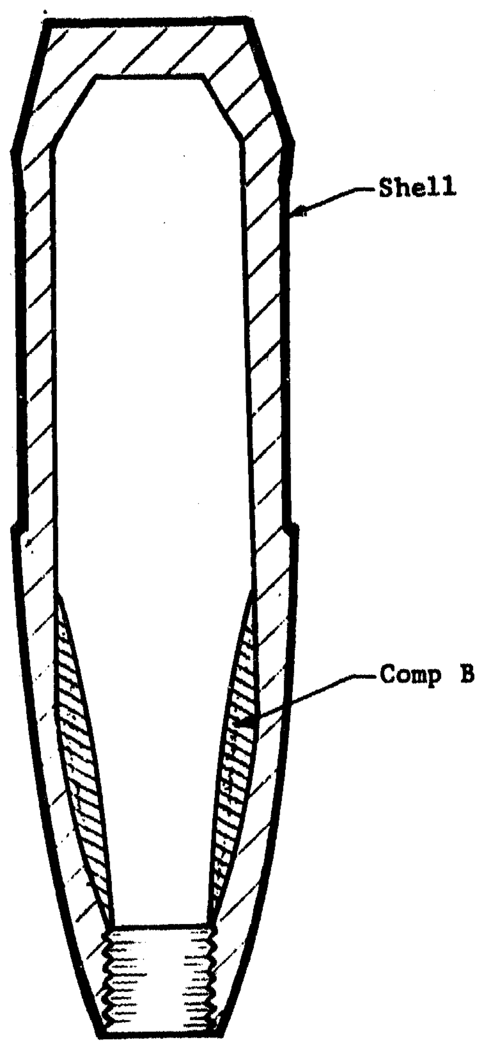


FIGURE 2

Recovery of Comp B Components

RDX

When the washout process was completed, RDX was retrieved from the bottom of the washout and the settling tanks. The recovered RDX is shown in Figure 3. This recovered RDX had a light yellowish color, and a sand-like crystalline form. The drying and the purity analysis of recovered RDX have not yet been done but samples will be supplied to Dr Harold Matsuguma at Doner NJ for analysis in his laboratory.

TNT

TNT would be recovered when the temperature of this toluene is cooled from 50°C to 20°C. When recrystallized from solvent, this recovered TNT will be free of RDX and wax contaminations. At the time of this report, the sensitivity study of the TNT-toluene has not been completed, thus, no attempt has been made to recover TNT from the toluene solution.

WAX

The wax in comp B will not be recovered with this process because of its marginal economic value. It will remain dissolved in the recycling solvent.

Conclusions

In conclusion, this study had demonstrated that the comp B explosives from 105mm projectiles and 3.5 inch rockets were successfully washed out and RDX was recovered, using toluene as the washout medium.

Separately recovered RDX (solid), TNT (in solution) from Comp B (105MM projectile) in 1 quart bottles.

This rapid washout was accomplished by the combined effects of mining action and solvation action of a warm solvent. The immediate and effective separation/recovery of RDX and TNT was achieved by the selective solubility of the organic solvent used.

The test results suggested that the organic solvent washout technology is versatile and can be readily adapted to other munition washout.

Finally, I would like to discuss briefly some of the possible advantages that can be derived from this technique, they are:

(1) The overall process of washout/separation is simplified and the production rates are increased.

(2) The separate recovery of explosive components is possible in a single operation.

(3) This technique could be adopted to other explosive washouts by simply changing organic solvent.

(4) The washout temperature and pressure are much lower than other methods, thus require much less energy.

(5) The maintenance requirement for the process equipment are reduced due to the non-corrosive nature of organic solvent used.

Future work planned includes optimization of equipment and the process. If ecconomic analysis then proves the value of the new method, a design of production facility will be completed.

CHEMICAL CONVERSION OF TEAR GAS (CS)

REPORT PRESENTED AT
DoD EXPLOSIVES SAFETY SEMINAR

BY

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INTRODUCTION

A large quantity of bulk packaged tear gas agent CS is designated for demil/disposal. ARRCOM records indicate a total amount of bulk CS in the Demil account of 2,300,000 pounds (Reference 1.). This quantity could increase by at least another million pounds.

The currently planned method for the disposal of bulk CS is burning in multiple stage incinerators (Reference 2.). This method not only results in the loss of a valuable raw material, but is also an energy expensive disposal process without economic return.

AEO has postulated and proposed a relatively simple chemical conversion process for bulk CS (tear gas), resulting in the non-toxic raw material, *o*-chlorostyrene, *o*-chlorocinnamic acid, and a by-product, ammonium sulfate.

Chemistry

1. Tear Gas (CS)

The generic nomenclature of the chemical agent CS is *o*-chlorobenzalmalononitrile. The structure of CS is given in Figure 1.

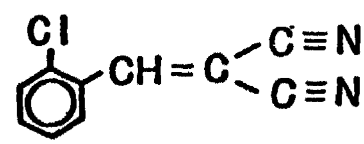


FIGURE 1 *o*-Chlorobenzalmalononitrile

This chemical compound contains two nitrile functional groups at the second position of the vinylic end of the molecule.

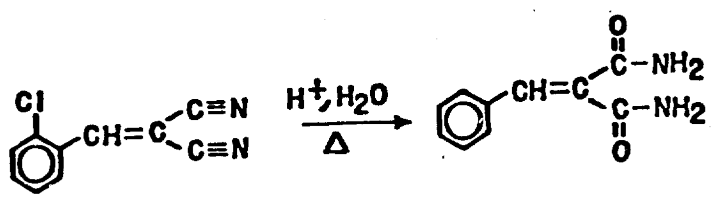
2. Proposed Chemical Conversion

Removal of these two nitrile functional groups effects the chemical conversion of bulk CS to *o*-chlorostyrene.

The overall process involves two reactions in series. The first step is an acid or base catalyzed hydrolysis of CS to o-chlorocinnamic acid. The second reaction is the decarboxylation of this intermediate product to give o-chlorostyrene.

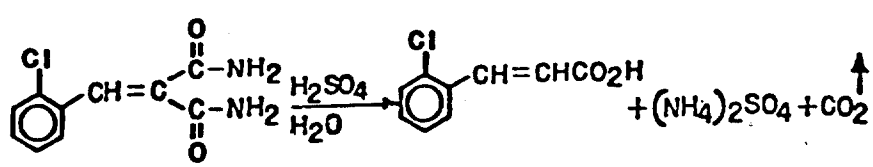
a. Acid Catalyzed Hydrolysis

When sulfuric acid is used as a catalyst in the hydrolysis reaction of CS, the initial product is the diamide formed by addition of H_2O to the nitrile groups as shown in equation 1,



(1).

but since amides are also hydrolyzed by acid, the free acid (o-chlorocinnamic acid), ammonium sulfate, and CO_2 gas are the final products from this reaction, as shown in equation 2.



(2)

b. Decarboxylation of O-Chlorocinnatmic Acid

The second reaction, the decarboxylation of o-chlorocinnamic acid to o-chlorostyrene, is facilitated by the nature of the resonance structures of the α,β -unsaturated free acid, and the ability of the ionic o-chlorocinnamic acid to disperse electron density over the entire structure of the molecule. Thus the decarboxylation reaction should proceed as shown in equation 3.

(3)

Experimental Procedures and Results

1. Acid Catalyzed Hydrolysis of CS

A 250 milliliter (ml), three neck round bottom flask was equipped with a water cooled reflux condensor, a mechanical stirrer, a heating mantle, a thermometer, and a variable transformer as shown in Figure 2.

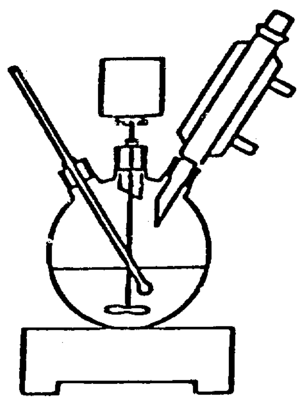


FIGURE 2 Hydrolysis Apparatus

Fifty ml of freshly prepared acid solution (70% v/v) was cooled in an ice bath to 30°C and added to the flask. While stirring the solution, five grams of CS was slowly added to the flask, producing a uniform slurry of CS and acid. The mixture was heated to 90°C and this temperature maintained until the slurry was completely dissolved, resulting in a clear amber colored solution. The temperature of the reaction mixture (amber solution) was then increased to 125-135°C where it began to reflux. When the solution had refluxed for one hour, a white solid began to form in the solution.

After four to eight hours of refluxing, the contents of the flask were decanted into a 1000 ml flask, diluted with 500 ml of cold water, and allowed to cool to room temperature. The mixture was filtered through a Buchner funnel to separate the solid from the filtrate which was collected and set aside for further treatment.

The solid was dissolved in a dilute basic solution and the insoluble impurities were removed by filtration. The resulting clear yellow solution was acidified with hydrochloric acid solution to produce a white solid. This mixture was then filtered and the purified solid product, which is *o*-chlorocinnamic acid, was collected and air dried.

The filtrate was transferred to 1000 ml beaker which was placed in an ice bath. The NH_3 gas was slowly bubbled in and reacted with the filtrate approximately one hour, producing ammonium sulfate crystals. The crystals were collected by filtration and air dried.

2. Results of Hydrolysis Reaction

a. Acid Concentration

The results of the four-hour reactions are shown in Table 2.

TABLE 2. Results of Hydrolysis of CS (with reaction time 4 hrs)

Run No.	H_2SO_4 Conc. (%)	Temp (°C)	CS (gms)	o-CCA (gms)	Conversion (mole %)
KA440	40	130-135	5.022	0.619	12.74
KA450	50	"	6.712	2.403	36.96
KA460	60	"	5.798	2.849	50.02
KA471	70	"	4.921	3.774	78.88
KA472	70	"	6.548	4.773	75.32
KA480	80	"	4.775		

*o-CCA=o-chlorocinnamic Acid

Data from Table 2 was plotted in Figure 3 showing the percent yield as a function of the sulfuric acid concentration while the reaction time was held constant at four hours. The rate of hydrolysis of CS increased linearly as the sulfuric acid concentration was increased from 40% to 70%, indicating that the rate of hydrolysis of CS is dependant on the acid concentration.

When the concentration of H_2SO_4 was increased to 80%, the predominant product was a polymeric material rather than the desired o-chlorocinnamic acid. Therefore no data for this concentration is given in Table 2.

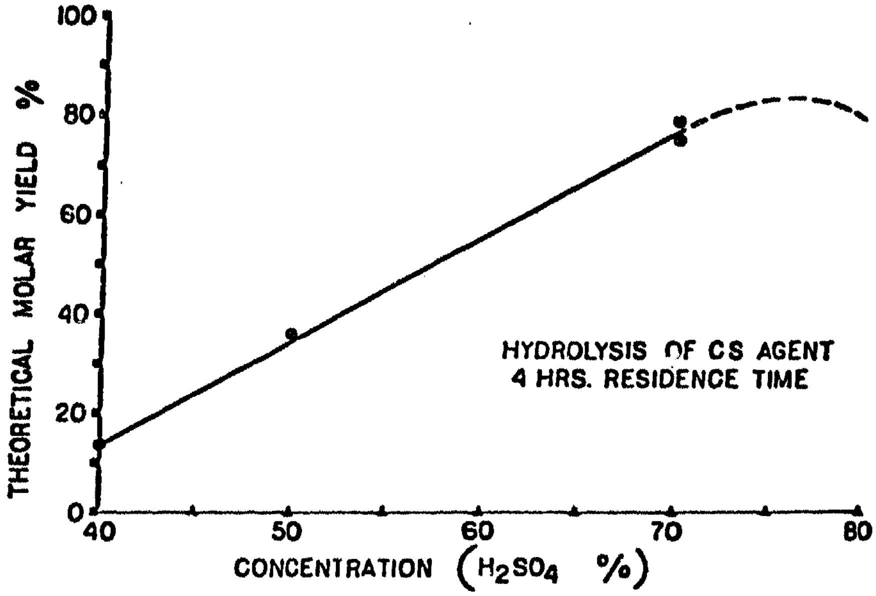


FIGURE 3 Percent yields as a function of Sulfuric Acid concentration

b. Reaction Time

The results of the reactions, where the sulfuric acid concentration was maintained constant at 70% while the reaction times were allowed to vary, are given in Table 3.

TABLE 3 Results of Hydrolysis of CS
(with 70% sulfuric acid concentration)

Run No.	Temp. (°C)	Reaction Time (Hours)	CS (grams)	o-CCA* (grams)	Conversion (mole %)
KA 170-1	130-135	0.5	5.223	3.042	60.13
KA 170-2	"	1.0	6.591	4.457	69.93
KA 270-1	"	1.0	5.461	2.910	55.14
KA 270-2	"	2.0	7.022	4.870	71.69
KA 470-1	"	2.0	4.941	3.774	78.88
KA 470-2	"	4.0	6.548	4.773	75.32
KA 670-1	"	4.6	6.477	5.648	90.17
KA 670-2	"	6.0	7.938	5.583	73.92
KA 870-1	"	6.5	4.537	3.717	84.46
KA 870-2	"	8.0	8.225	6.223	78.16

*o-CCA = o-chlorocinnamic Acid

Data from Table 3 is plotted in Figure 4 showing the percent yield as a function of reaction time while the sulfuric acid concentration of each run was held constant. Figure 4 indicates that the maximum yield (90%) was obtained when the sulfuric acid concentration was 70% (V/V) with the reaction time of five hours, and the temperature being maintained at 130-135°C.

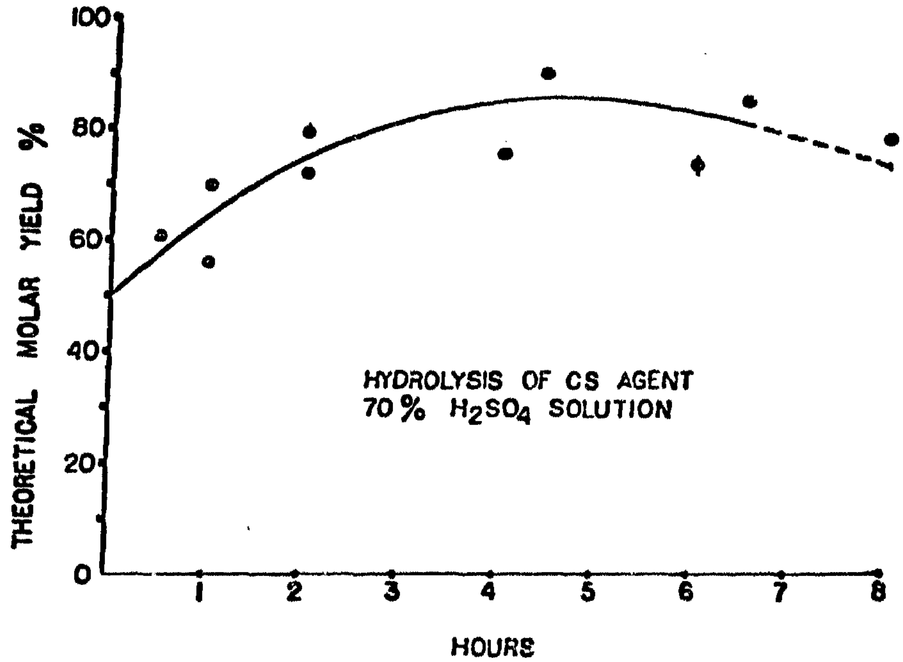


FIGURE 4 Percent yields as a function of Reaction Time

3. Decarboxylation of o-Chlorocinnamic Acid

Seventy-five grams of air dried o-chlorocinnamic acid obtained from the acid catalyzed hydrolysis of CS was mixed with 20 grams of NaOH.CaO and 5 grams of copper powder. This mixture was added to a 200 ml, two neck round bottom flask.

The flask was initially attached to an air-cooled reflux condensor and a temperature gauge (range of - 10°C to 500°C), and was placed in a heating mantle.

The mixture was gradually heated to the melting temperature of o-chlorocinnamic acid (200°C), and maintained at that temperature until all of the acid had melted, producing an amber liquid. Then the temperature was increased to 270°C.

When the decarboxylation reaction started, a white vapor was evolved, and it solidified on the inside surface of air cooled reflux condensor.

The solid in the condensor was soon dissolved by the refluxing action of the product, and came back into the reaction flask. After all the white solid had dissolved, the air-cooled reflux condensor was quickly replaced with a water-cooled distillation condensor which had a collection bulb attached. The oily product collected had no color initially, but darkened as the decarboxylation reaction progressed. The temperature of the material in the reaction flask was increased from 270°C to 460°C during the three hour decarboxylation reaction time. When the reaction was stopped at 460°C, the oil coming over the distillation column had a light brown color.

4. **Results of Decarboxylation Reaction**

a. Reaction - three decarboxylation reactions were run, and the results are summarized in Table 4.

TABLE 4. Results of Decarboxylation of o-Chlorocinnamic Acid

RUN NO.	1	2	3
o-chlorocinnamic acid (moles)	0.41	0.44	0.38
o-chlorostyrene (moles)	0.14	0.13	0.16
Yield (molar percent)	34.15	29.55	42.11

The average yield of product was 35.27%. The residue is a mixture of polymeric products and other materials. No attempt was made at this time to recover a product from the residue.

5. Identification and Analysis of Products

The instrumental analysis of all products were performed using the following instruments: a) a Varian-EM 390-90 Nuclear Magnetic Resonance Spectrometer; b) a Hewlet-Packard 5982-A Mass Spectrameter; c) a Perkin-Elmer 457 Infrared Absorption Spectrameter; d) a Waters M-600 UV-254 High Pressure Liquid Chromatograph; e) a Beckman GC-2 Gas Chromatograph; and f) a Thomas Hoover Capillary Melting Point Apparatus.

Pilot Plant Study

1. Plant Layout

Based on the results obtained from the laboratory study, a pilot plant was designed and constructed. This pilot plant has the process capacity of 8 to 16 pounds bulk tear gas per day. The pilot plant concept and the flow chart are given in Figures 5 and 6.

2. Operation Procedures

Bulk CS which is contained in a multilayer paper bag is placed in the glove box. An operator, manipulating from the outside of the glove box, opens the bag and dumps the CS to the circulating sulfuric acid.

The mixture is pumped into a preheater/reactor where the mixture is heated to the temperature of 90°C, for 30 minutes. Then the solution is transferred to the second reactor and reacted for 8 hours at the temperature of 125°C.

The reacted material is then pumped into the holding tank and is diluted with cold water. Then it is centrifuged next, to separate and recover *o*-chlorocinnamic acid from the solution. The *o*-chlorocinnamic acid is placed in a forced air oven and dried. The solution is pumped into the ammonolysis tank, and NH_3 gas is bubbled in to react with the excess acid, producing additional ammonium sulfate.

Dried *o*-chlorocinnamic acid is mixed with a catalytic amount of copper sulfate and soda lime and charged into the decarboxylation reactor.

The temperature of the reactor is gradually increased to 370°C and maintained at this temperature until reaction is completed. The decarboxylated product, *o*-chlorostyrene, is condensed into a dark yellow oil and collected.

3. Results of Pilot Plant Study

Results from the pilot plant operation showed that the hydrolysis and decarboxylation reaction proceeded smoothly and the over all yield at the time of this report was 55%.

FIGURE 5

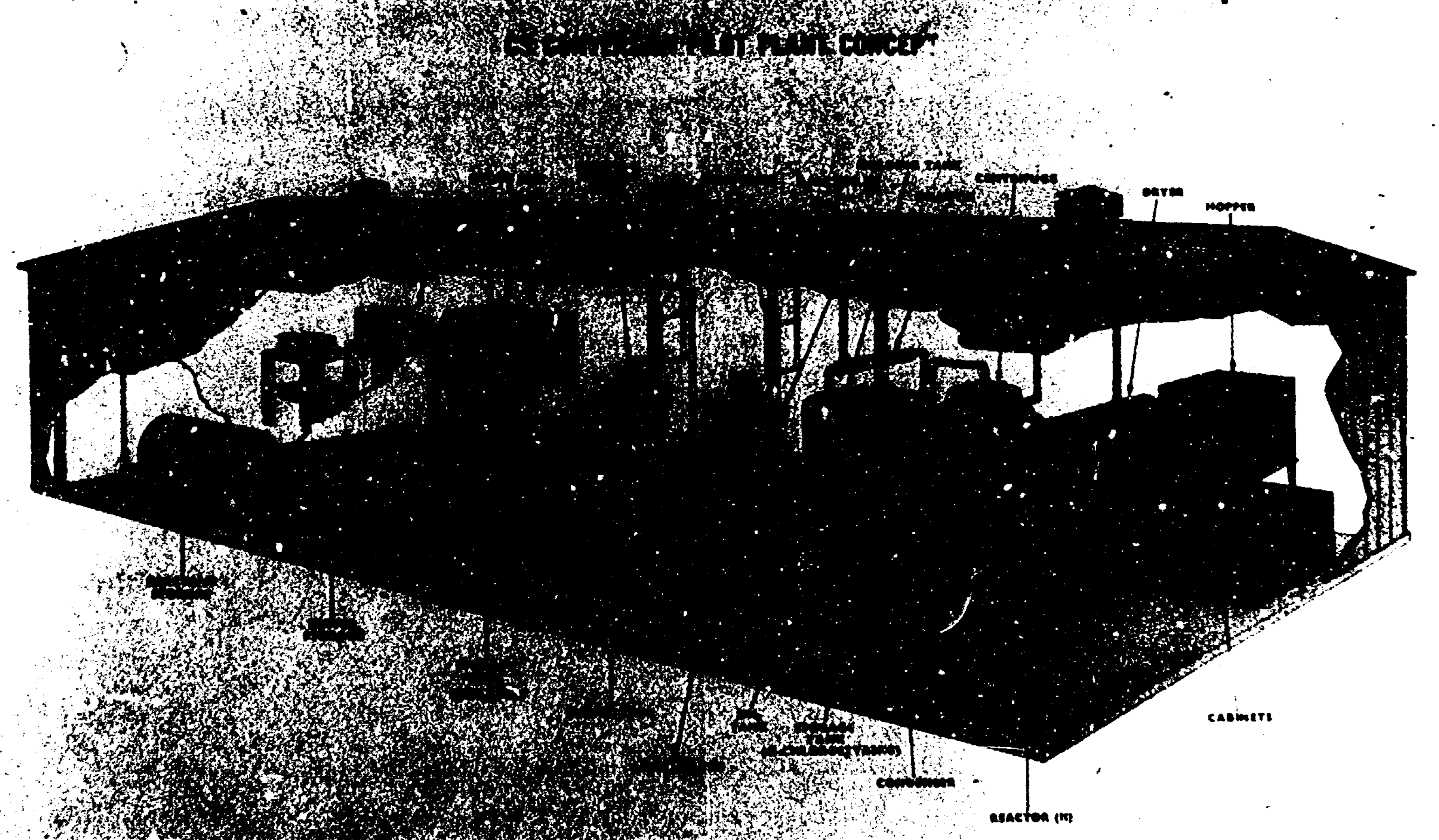
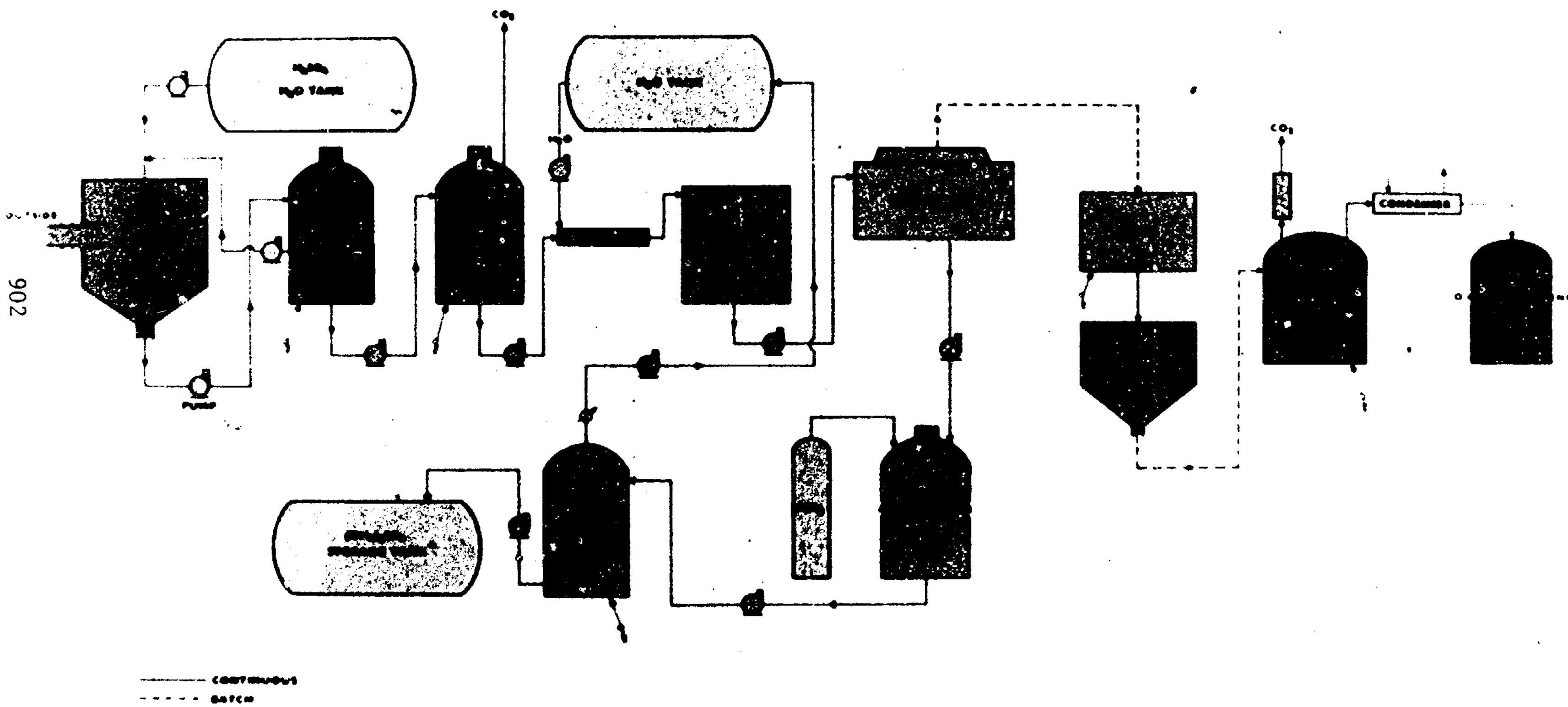


FIGURE 6

FLOW CHART CS CONVERSION PILOT PLANT



MARKET SURVEY

A preliminary market survey was conducted jointly by AEC and the Purchasing and Contracting Division, TEAD. Results of this survey were that the present market for o-chlorostyrene is undeveloped due to the high cost and the limited supply. However, it is anticipated that if this project begins to produce o-chlorostyrene, at an affordable price, a more active market and usage would be developed.

CONCLUSIONS

1. Laboratory Work

Conversion of CS to o-chlorostyrene was facilitated by two step reactions, 1) hydrolysis of CS; followed by 2) catalytic decarboxylation of the intermediate product (o-chlorocinnamic acid).

The first reaction, the sulfuric acid catalyzed hydrolysis of CS has produced o-chlorocinnamic acid. The reaction parameters, the acid concentrations, the reaction residence times, and the reaction temperatures were varied respectively, from 40% to 80%, from 30 minutes to 10 hours, and from 90°C to 135°C. A yield of 90% was obtained when CS was reacted with 70% sulfuric acid for five hours while the temperature was maintained at 130-135°C. Ammonium sulfate was the by-product from this reaction.

The second reaction, the catalytic decarboxylation reaction of o-chlorocinnamic acid has produced o-chlorostyrene and CO_2 gas. Two catalysts, NaOH.CaO and Cu (powder) were tried to increase the reaction rates of decarboxylation at this time. An average yield of 35% was obtained from three decarboxylation reactions tried.

2. Pilot Plant Study

The experimental work conducted at the pilot plant verified that the above reactions are feasible and can be reproduced on a production scale operation. An overall conversion rate of 55% was achieved during this pilot plant study. A recenly completed economic analysis based on data acquired in operation of the pilot plant has proven the process to be very cost effective.

REFERENCES

1. JCAP Demilitarization/Disposal Handbook, Volume 1, 30 September 1978.

2. Joint ARRCOM/DESCOM Study on Conventional Ammunition Demilitarization Facilites and Capabilities; Final Report, 31 August 1978.

WHITE PHOSPHOROUS MUNITION RECLAMATION

BY:

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TOOELE ARMY DEPOT, UTAH

INTRODUCTION

The purpose of this paper is to present the Army's program for reclaiming White Phospherous (WP) from various types of WP filled munitions that are either outdated or obsolete.

At the present time there is a relatively large quantity of WP munitions that have been placed in the demil inventory with more scheduled to be released for demil in the near future. The following table lists the current WP munition demil inventory which totals some 4000 tons.

WHITE PHOSPHOROUS INVENTORY

LOCATION		QUANTITY (TONS)
Ft. Wingate		2000
Hawthorne		1100
Lex-Bluegrass		250
Red River		200
Sierra		150
Others		380
	TOTAL	4080

The objective of the current program is to provide a system to demiliterize the WP inventory through controlled incineration to form Phosphorous Pentoxide and then produce a saleable agricultural grade Phosphoric Acid through water hydration processes.

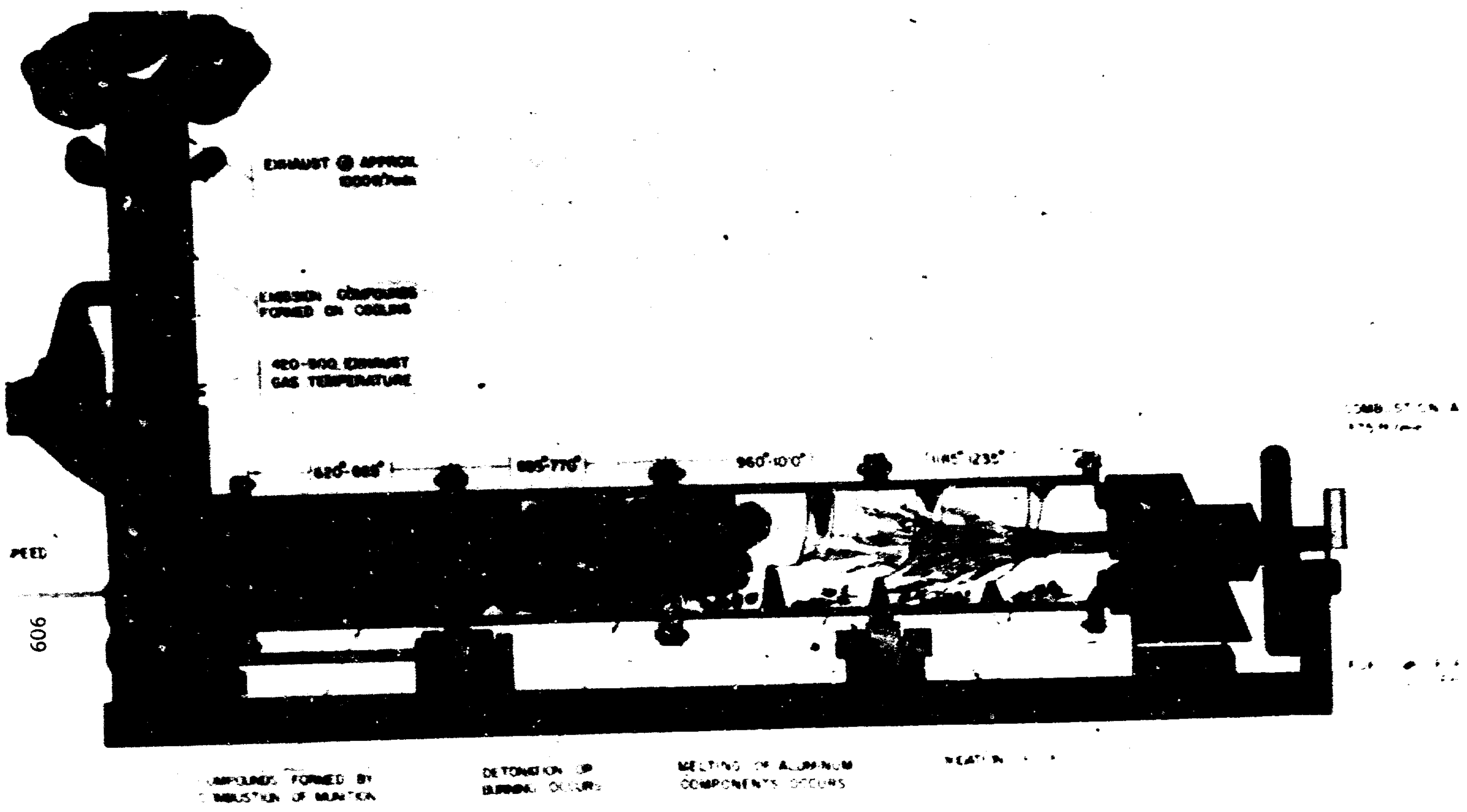
Process Development

Some twenty-four years ago, the Ammunition Equipment Office developed what is known as the APE 1236 Deactivation Furnace. The APE 1236 Furnace shown in Figure 1 is a retort furnace with internal flights which carry the munitions or explosives through the furnace. A single burner is located at the munition exit end of the furnace for temperature control. The combustion products exit through the stack at the live munition feed end of the furnace. It is desired that the munition begins burning or detonates near the center of the retort. The location where the burning or detonation occurs is controlled by the speed of the retort and the burner temperature. Items are fed into the furnace through an appropriate feed system from a location in the feed room. Personnel are protected by the barricade wall between the furnace and the feed room. The demiliterized metal scrap is dumped from the burner end of the furnace. Further details on the furnace, its operations, and the munitions and bulk explosives that it has been used for are presented in other papers presented by AEO at this Explosive Safety Seminar.

Incineration Development Tests

An objective of the current program is to use the APE 1236 Furnace to provide controlled incineration of WP munitions. To accomplish this, it was necessary to determine methods for feeding and processing the munitions to attain controlled combustion rates.

The first munition tested was a 3.5 inch rocket head assembly. The munition was fed whole and intact into the furnace, thus preventing ignition of the WP until the munition reached its rupture temperature. When the munition ruptured, the WP was released as a vapor and was rapidily oxidized-primarily at the top of the furnace stack. Although the burning was contained, it was not satisfactory for downstream process requirements. The round that passed through the furnace was clean inside and free of the slag or oxide which is typical of open air WP burns.



FURNACE DEACTIVATION

FIGURE 1: APE 1236 DEACTIVATION FURNACE

The next series of tests conducted was also with the 3.5 inch rocket except that a hole was punched in the rocket exposing the WP. The hole size ranged from 1/8" to 3/8" diameter. The operation was conducted under water to be assured that the munition would not oxidize prematurely. The munition, containers and water were fed into the furnace. Ignition of the WP occurred and the WP was consumed at a slower rate over a longer period of time (2 to 3 minutes). The maximum burn rate calculated was 3.2 lb WP/minute. This group of tests indicated that a controlled burn could be established by the manner in which the WP is exposed to the flame front. Several rounds were opened after going through the furnace and were found to be clean inside.

The next series of tests were made using the 105 mm projectile. The 105 mm round has 4 lbs of WP as compared to the 2.2 lbs WP in the 3.5 inch rocket. The round was first sectioned into two pieces each containing approximately 2 lbs of WP. The sectioned round, container and water were fed into the furnace. Again the WP burned at a controlled rate and burned clean with very little residue. It should be noted that the rounds were sectioned with a cold saw. The cutting coolant was the only water solution used to control the WP from ignition during the cutting operation. The sections were then placed in water filled containers and transported to the furnace. The burn time was found to be approximately 1.5 minutes/half section.

The 105mm round was then sectioned such that essentially all the WP was in one section. Again the sectioned round, containers and water were fed into the furnace, only this time the feed was 4 lbs. WP per section. Again the WP burned at a controlled rate with burn times between 2 to 2.5 minutes per section. The munition burned clean with very little residue.

Tests were next made using the cold saw to just barely cut into the round to expose the WP. This cut was to simulate a punched hole. The cut was located at the nose end of the round with all of the WP behind the cut. The complete round, container and water were fed into the furnace. The WP

burned at a controlled rate with a burn duration of approximately 3 minutes. The munition burned clean with the least amount of residue noted in the 105mm series of tests. Burn rates up to 2.8 lbs. WP/minute were attained.

The next series of tests were conducted using 4.2 inch mortars (M-328A1) and M-34 grenades. The 4.2 inch mortars were run in the same configuration as the 105mm projectiles (cut in half, nose cut off, and slotted). Figure 2 shows the 4.2 inch mortar being slotted. The sections were not placed in the furnace under water. Figure 3 shows the slotted 4.2 inch mortars prior to entry into the furnace. Burn times for the slotted 4.2 inch mortar was between 3 and 4 minutes. Burn rates for the slotted munition were found to be 5.95 lbs WP/minute. At the end of the burn the rounds were clean as can be seen in Figure 4.

The grenades were punched using the press shown in Figure 5 prior to entering the furnace. Figure 6 shows the punched round. Burn times for the punched grenades were found to be between 1 and 2 minutes. Following the incineration process the rounds were clean. This can be seen in Figure 7.

The mode of burn appears to be that the white phosphorus is heated inside the round with only minor burning at the surface until the WP melts (111°F) and starts to run out of the round. The WP is then vaporized and burns or runs onto the inside surface of the retort and burns. This is substantiated by the condition of the punched munitions that have gone through the furnace. The insides are spotless, while the outsides have minimal slag and other deposits on them.

The results have demonstrated that the burning process can be controlled by the size of the punch or size of the section cut, not the size of the round.

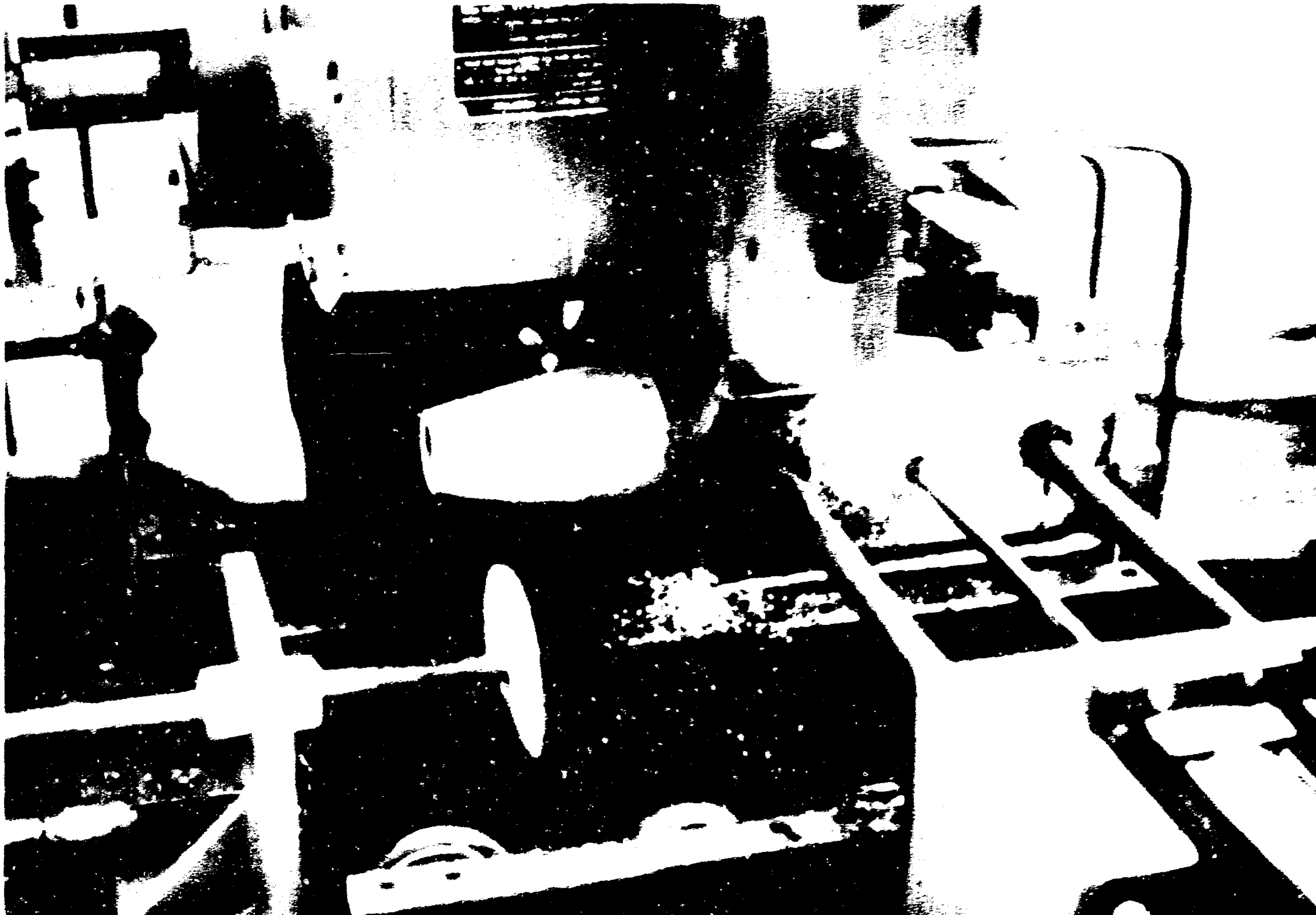


FIGURE 2: SAW SLOTTING 4.2 INCH MORTAR

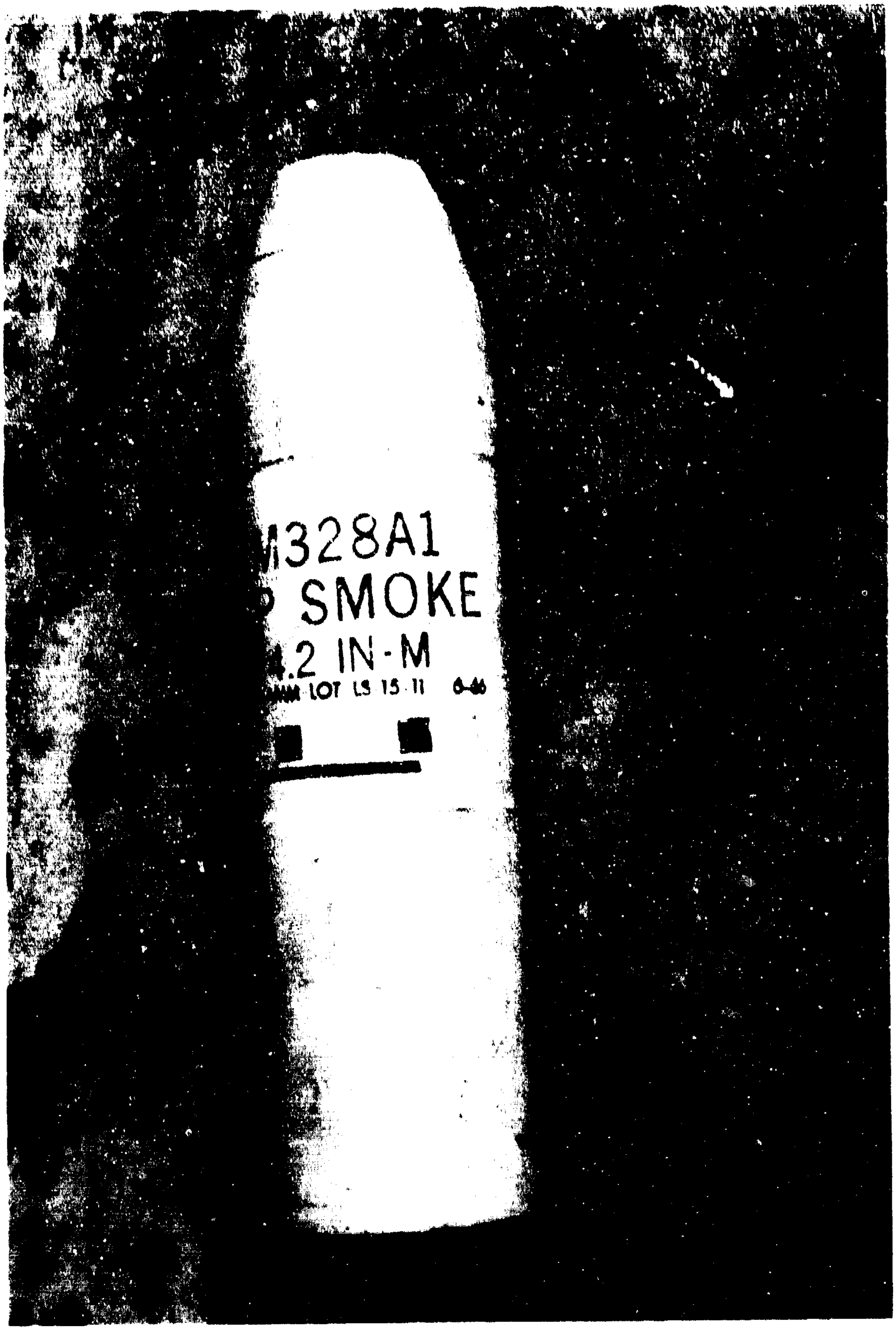
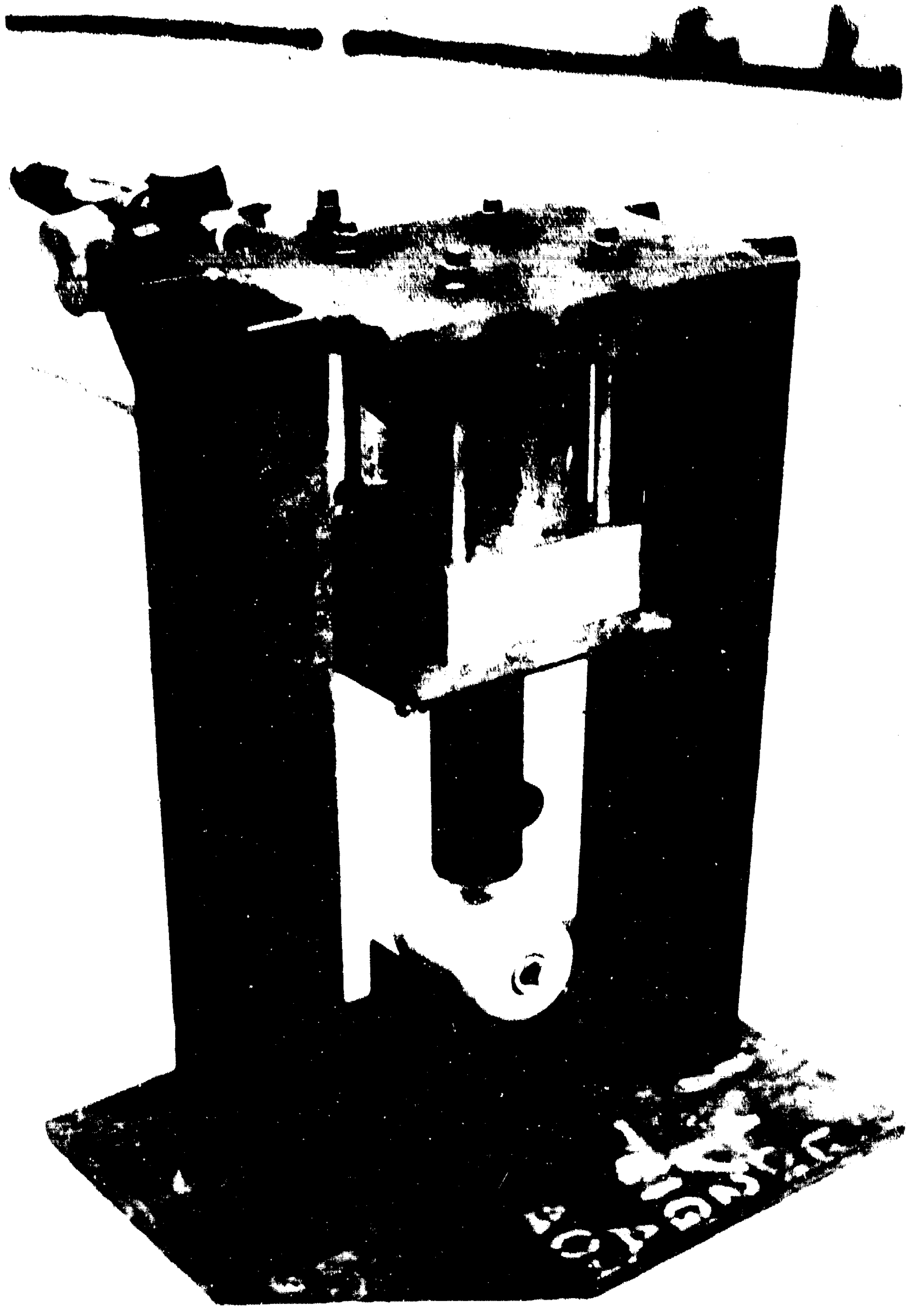


FIGURE 3: SLOTTED 4.2 INCH MORTAR

FIGURE 4: SLOTTED 4.2 INCH MORTAR AFTER BURNING



915 FIGURE 5; GRENADE PUNCH

FIGURE 6: PUNCHED GRENADE

FIGURE 7: CLEAN GREANDES AFTER BURNING

Phosphoric Acid Plant Design

Based on the success of the above tests, a survey was made of a number of companies producing phosphoric acid to determine the processes and controls used. Companies were also contacted to determine the marketability of agricultural grade phosphoric acid.

It was determined that the basic equipment required to produce phosphoric acid is state-of-art. It was also determined that there is a market for the phosphoric acid.

The AEO was given the authority by ARRCOM to design a phosphoric acid plant. Originally a permanent plant was to be built at Ft. Wingate which has the largest WP inventory. An economic analysis was made to evaluate the costs of shipping WP munitions from various storage locations to a central demil site. It was determined that it would be economically advantageous to the government to build a transportable phosphoric acid plant which would be relocated at 4 or 5 depots having the largest workload. This would require that only the water hydrating portion of the plant be transported since each of the demil sites where the transportable plant might be located has an existing APE 1236 Deactivation Furnace.

Plant Design Parameters

Based on the preliminary WP incineration tests and calculations made to determine steady state WP burn rates under optimum control conditions, a maximum plant feed rate of 480 lb/hour WP was specified. This will result in a phosphoric acid production rate of 2000 lb/hr. The plant is to be designed to handle all types of WP munitions in the WP inventory.

Feed System Design

The incineration tests demonstrated that the burning process can be controlled by the size of the punched holes in the munitions. The feed system for the WP plant will utilize equipment which will position the WP munition at the entrance of the Deactivation Furnace. The munition will be punched and immediately pushed into the furnace to minimize the possibility of burning outside the furnace. The munition will be fed to the punch location by a positive feed type system (or robot) from the munition loading area behind the barricade wall. The entire munition punch area will be under negative pressure from the furnace retort.

Figure 8 shows the operation of a positive feed system designed by the AEO. This system is also described in detail in another paper being presented at the current Explosive Safety Seminar. The basic objective of the positive feed system is to safely feed bulk explosive through the barricade wall and into the furnace. The explosive is loaded from the operator's station, moved through the barricade wall to the end of the furnace, transfered sideways to the feed position of the furnace and pushed into the furnace. The system is controlled automatically with interlocks so that a deflagration or detonation cannot be transfered to the operator location. With a system of this type, the WP punching would be accomplished just before the munition is pushed into the furnace.

Phosphoric Acid Plant Layout

The basic layout of the Phosphoric Acid Plant is depicted in Figure 9. The system consists of the following major subsystems: deactivation furnace, water hydrator, variable throat venturi, separator, concentrated acid tank, dilute acid tank, overflow tank, exhaust fan and stack, storage tank, (if possible a transportable truck tanker) and associated pumps, valves and controls.

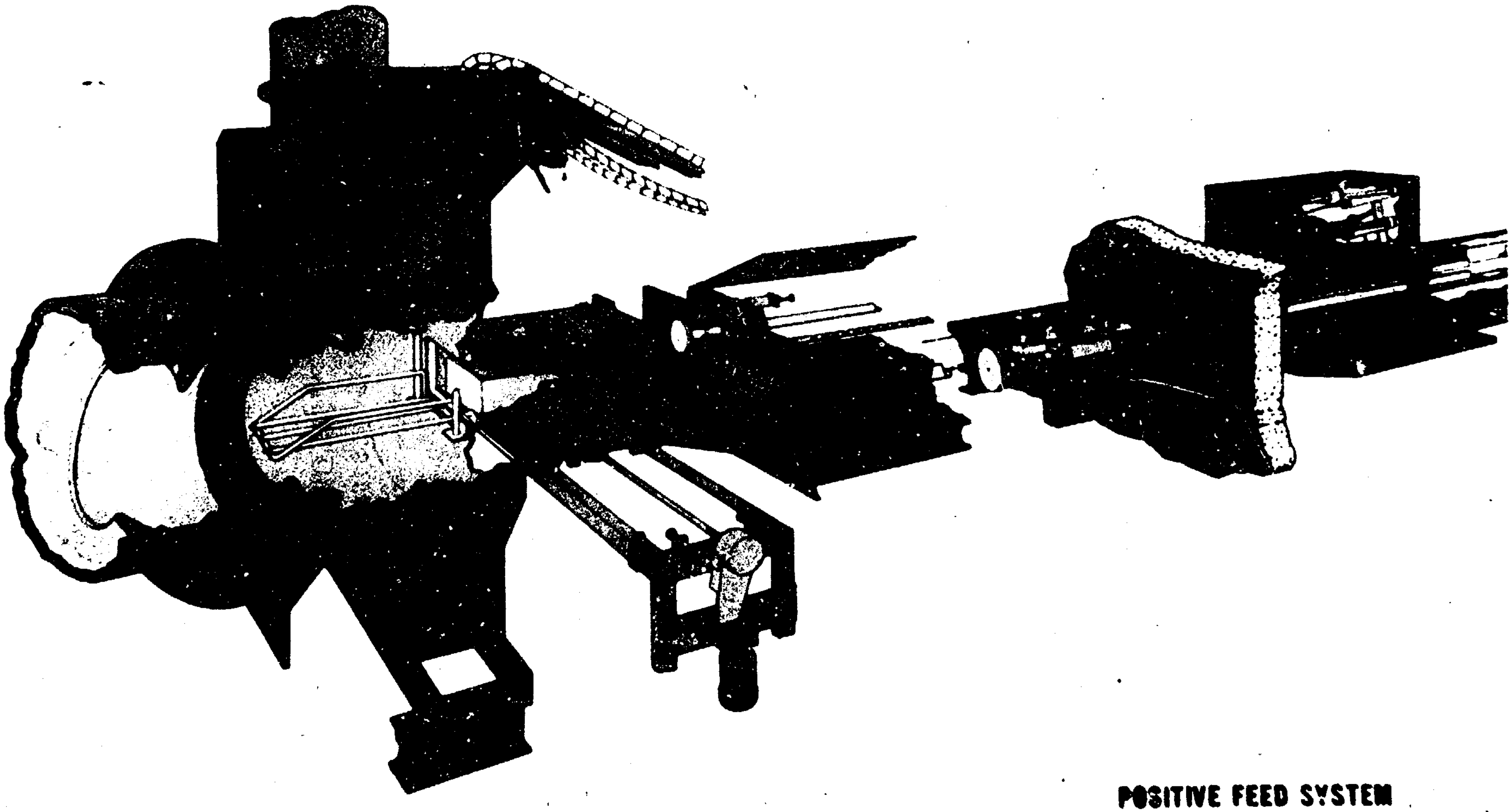


FIGURE 8: POSITIVE FEED SYSTEM

A brief description of the Acid Plant operation follows. The Phosphorous Pentoxide (P_4O_{10}) passing from the deactivation furnace passes through the water hydrator. The water hydrator is basically a tank with a series of internal shower heads. Acid from the concentrated acid tank (right of hydrator) is pumped through the hydrator. When the acid concentration reaches approximately 75%, as determined by a specific gravity meter, the acid is pumped into the storage tank (truck tanker) for shipment. The (P_4O_{10}) not scrubbed from the exhaust gases in the hydrator pass through the variable throat venturi. The venturi system located between the large hydrator and separator is designed to operate with a 60 inch W.C. pressure drop-essentially fracturing the liquid into small particles and allowing good contact between the gas and liquid to form Phosphoric Acid. The separator acts to separate the liquid from the gas stream. Acid from the dilute acid tank is used to circulate through the variable throat venturi and is also used for make-up in the hydrator when concentrated acid is pumped to the storage (shipping) tank. An over flow tank is provided below ground level in case either of the acid tanks overflow due to a control malfunction. The exhaust gases from the separator are then passed through the fan and out the exhaust stack. The acid hydration system is designed to operate primarily on gravity flow except when pumping from the tanks to the hydrator, variable throat venturi, and storage (shipping) tank.

Transportability Design

Since APE 1236 Deactivation Furnaces are located at each site being considered for installation of the transportable plant, it will not be necessary to move the furnace. To make the remaining system transportable, the major subsystems will be installed on skids for ease of shipment. Current plans call for locating the hydrator, venturi and separator on one skid, the concentrated and dilute acid tanks on one skid, the fan on a skid, and the over flow tank on a skid. Various pieces of ductwork will also be stacked together for shipment. It is seen from Figure 9 that the components listed for each skid are located close to each other in the plant layout

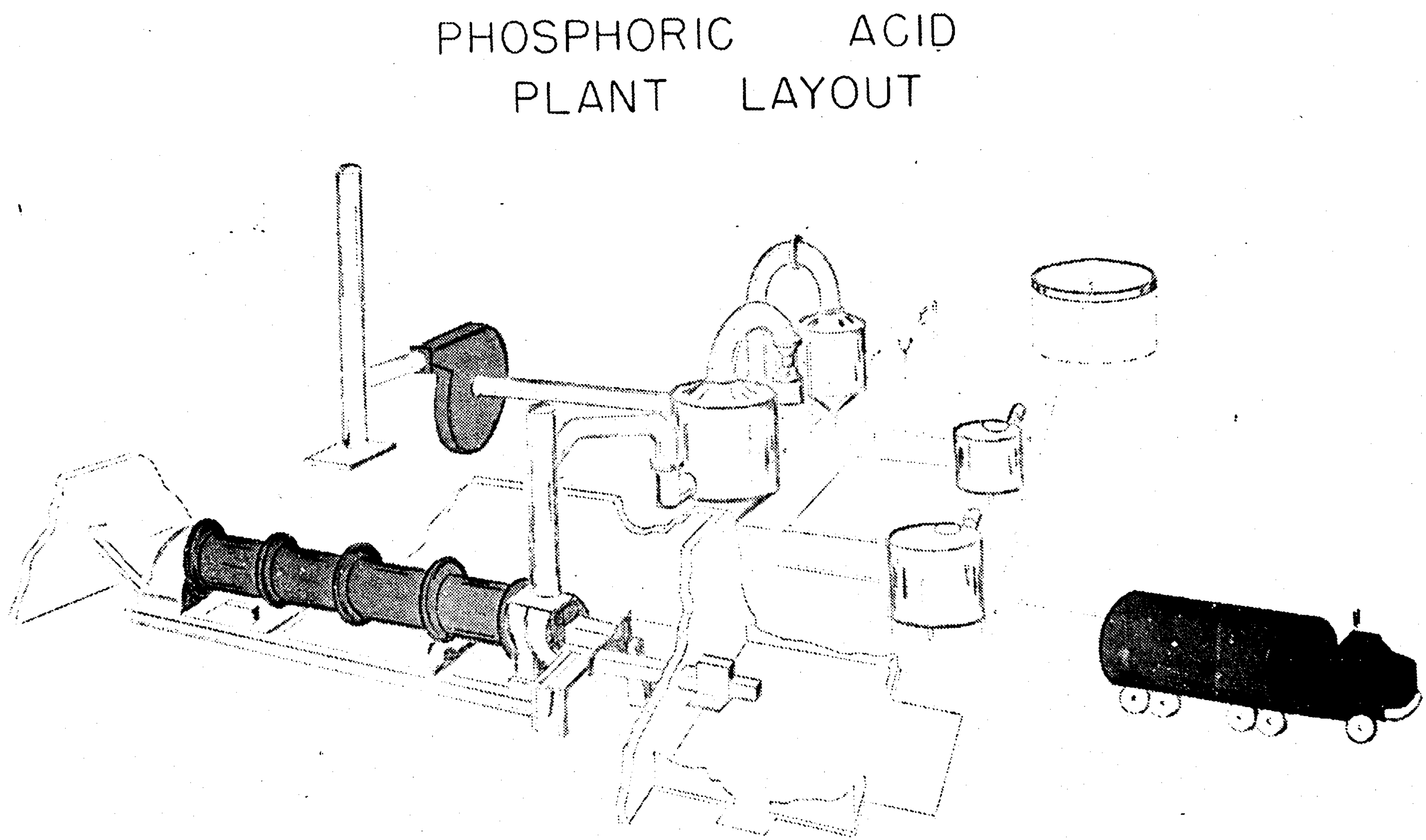


FIGURE 9: PHOSPHORIC PLANT LAYOUT

for ease of locating them on skids. It is not planned that the units will be removed from the skid for installation.

The facility is being designed so that it can be shipped by either rail or truck. This will require that certain sections of ductwork be disconnected between subsystems and that the hydrator and separator systems be mounted on expandable legs so the units can be collapsed for ease of shipment.

Figure 10 depicts how the facility may be placed on a 80 feet by 10 feet railroad car for shipment.

CONCLUSIONS

The following conclusions can be made concerning the design of the phosphoric acid plant.

1. The technology for the incinerator, feed systems and water hydration processes are basically state-of-the art technology.

2. The WP munitions can be successfully burned in a controlled manner by the size of the punched hole or section cut.

3. There are important payoffs to the government from the conversion of WP to phosphoric acid.

a. The elimination of open burning.

b. The elimination of the expense associated with moving large quantities of WP.

c. The production of Phosphoric Acid resulting in a financial payback to the goverment.

d. The process complies with the requirements of the Resourse Conservation and Recovery Act.

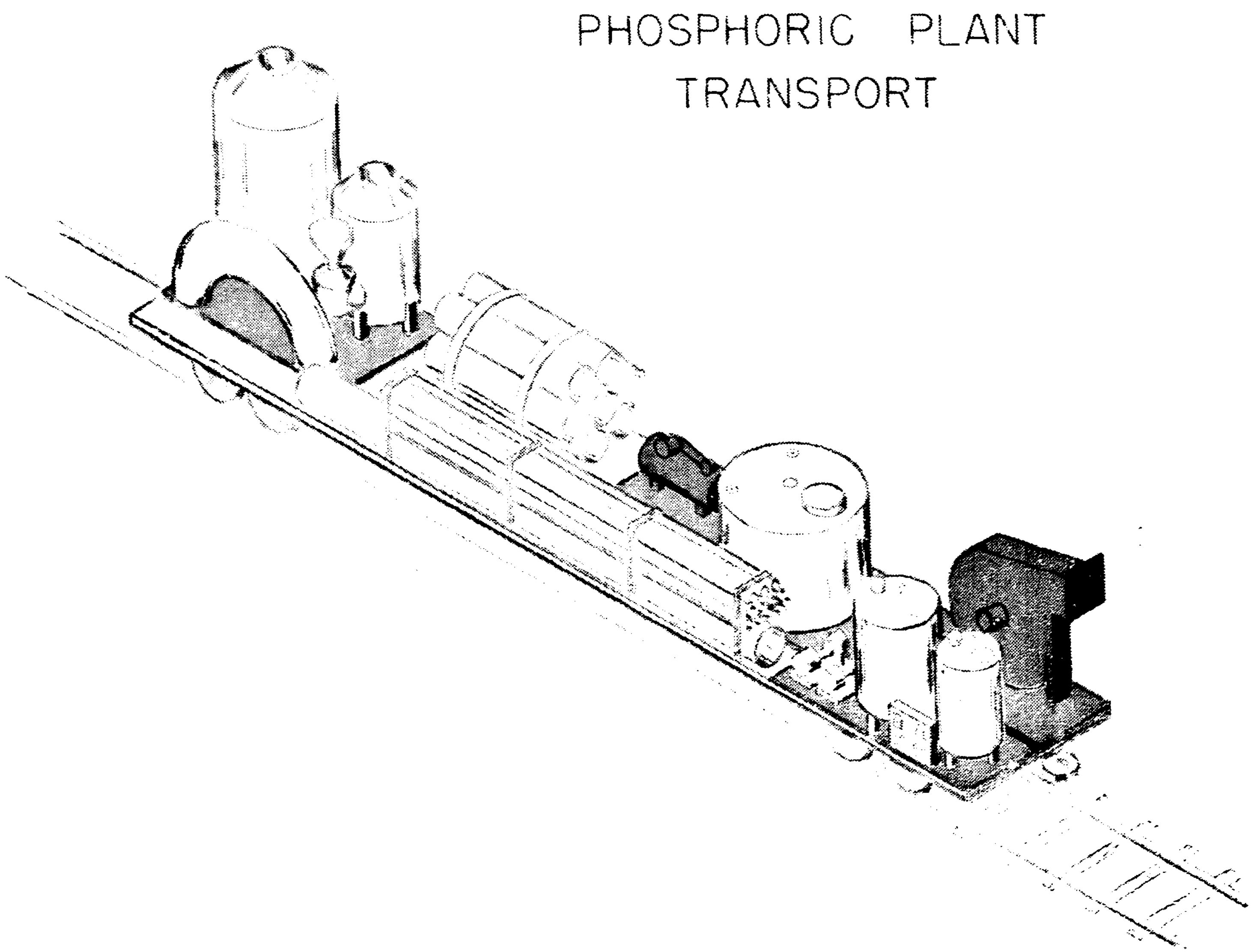


FIGURE 10: RAILROAD CAR SHIPMENT LAYOUT

MUNITION DEGRADING WITH PROPER BARRICADING

BY:

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TOOELE ARMY DEPOT, UTAH

Munition degrading is a preparatory step required by many thermal demil processes. Its purpose is to render the munition non-detonable, at least to the extent possible, and to promote burning of the energetic material within the item. It is a physical operation which either demils the item or prepares it for demil.

Degradation of munitions has, in the past been performed for both demil and investigative purposes; however this paper will deal only with degradation associated with demil.

In the days of open air burning and detonation, munition degradation was rarely required. Items to be demilled were merely detonated at the demolition ranges found at most military installations. As clean air standards came into the picture, furnace/incinerator burning became the rule rather than the exception, since it provided a means of controlling and cleaningthe effluent gases prior to release to the atmosphere. Additionally, burning in demil furnaces provided a means of efficiently collecting metal scrap from burned out munitions, which is valuable for resale.

Most munitions have an external case (usually metallic) enclosing the energetic material, and it is the presence of this case which causes item detonation (cook-off) in a demil furnace. If explosive quantities are sufficiently large, these detonations will damage the furnace. Detonation of items containing small HE quantities, such as small arms, percussion

primers, and lead charges, however, can be tolerated by most ammunition disposers.

Almost all metallic cased munitions can be made to burn out rather than detonate by sufficiently breaching the case and thereby exposing the energetic material to direct flame and heat in the furnace. This breaching is the operation we refer to as munition degradation. On some munitions, only a very small opening is required to preclude detonation.

Various methods have been used to open up munitions for thermal demil, including punching, shearing, crushing and several different sawing techniques. Machine dissassembly has also been used in some cases, but will not be covered in this paper. In general, dissassembly of munitions to expose the energetic material is not a workable method for demil, since most munitions are assembled with somewhat non-reversable methods, such as staking of threaded joints and use of joint cements such as loc-tite, and Pettman or NRC compounds. Disassembly is indicated in most rennovation operations in order to be able to reuse components, but for demil, where part damage can be disregarded, more violent degrading methods can be used, usually with a savings in production time and machine sophistication.

Degrading munitions by subjecting them to violent action and undue force is not what anyone would consider normal procedure. Usual practice calls for handling munitions with care and indeed many accidents have occured due to rough handling of explosive items. Consequently some of our proven degradation methods have encountered initial skepticism.

The selection of a degradation method calls for rather delicate design. We usually do this in two phases, the first phase is a paper study of the detonation mechani cs of the subject munition. During this phase we draw on our previous experience with similar items, if any, and assess the degree of violence to which we can subject the item. This phase defines candidate methods to be tried, such as punch or shear blade configurations, forces and

speeds to be used, total energy inputs, and point of attack on the munition. The candidate methods are then rated, and the second phase, testing, is initiated.

Testing is usually done as a walk-a-around operation using a single cavity test fixture. The fixture shown in Figure 1 has been used for degradation studies on a number of different munitions. The hydraulic cylinder shown o n this fixture is capable of mounting a variety of punches or shear blades, and the table portion is universally configured to accomodate a wide assortment of munition holding/clamping devices.

In most of the demil systems designed by our Ammunition Equipment Office, the major process step is a pass through the deactivation furnace, which was mentioned in several previous papers. The deactivation furnace, as you may recall (figure 2) consists essentially of a tubular steel retort 3 feet in diameter by 20 feet long with an internally cast screw flight. As the retort rotates, the screw flight conveys the munitions through. The furnace is fired by a burner at the discharge end and a baghouse pollution control system is installed to control emissions.

Munition degradation to breach a metallic case usually calls for the application of undue force, and the potential for detonation is fairly high. Consequently the degradation machine must be properly shielded for operator protection, or made a walk-around operation. Walk-around operations are normally slow, and we have endeavored to provide protective shields for most of our degradation machines.

Machine shields must meet MIL-STD 398 entitled "Shields, Operational for Ammunition Operations, Criteria for Design of and Test for Acceptance", Nov. 76. This standard requires that all shields be explosively tested using the worst case munition plus a 25% overcharge, and details the acceptance criteria. Shields meeting this standard afford complete operator protectio n as opposed to previous criteria which merely minimized hazards.

One requirement is that the shield itself (or any portion thereof) must not move, under blast loading, in a manner hazardous to personnel. We have had unusual experiences with several shields which posed this hazard. In one case (Ref: APE 1222 machine) the operator was required to manipulate a 6 lb. tool from the safe side of the shield. This tool extended through the shield and was in contact with the explosive element inside the shield. The kickback of the tool into the operator had to be considered to determine the degree of hazard. An explosive test was conducted, and by use of high speed photography, the maximum tool velocity was determined, in this case 11 fps. Information obtained from the Lovelace Foundation in Albuqurque showed that we were below the injury threshold value for blunt trauma and could consider the operation safe. (This was a renovation, not a demil operation.)

M34 CLUSTER BOMB DEMIL

One of our early munition degradation jobs was a part of the M34 Cluster Bomb demil project at Rocky Mountain Arsenal. This cluster bomb contained 76 individual M125 bombs as shown in figure 3. These bombs were about 12 inches long by 4 inches in diameter and had a central fuzed burster containing .55 lbs. of tetryl. The annulus between the burster and the casing was filled with GB chemical agent.

It was proposed to process these bombs through a deactivation furnace after the chemical agent had been drained. The AEO was assigned the task of designing a process to prevent detonation of the burster charge, since detonations of this magnitude would damage the furnace.

The solution to the problem proved to be a shear station ahead of the furnace at which the burster was completely severed from the fuze. Figure 4 shows typically the sheared M125 bomb.

A flat shear blade was used which penetrated the bomb side wall, then sheared the burster, but did not penetrate the far side of the bomb. This

left the sheared off portion of the burster as a loose piece inside the bomb body.

During the course of this operaton, over 20,000 M34 clusters were demilled, each containing 76 M125 bombs, which amounts to over a million and a half sheared and burned bombs.

M-55 CHEMICAL ROCKET DEMIL EQUIPMENT

One of the more complex munition degradation machines built by the AEO is the Rocket Demil Machine (RDM), figure #5. Designed during the 70's, this equipment is now in operation at the CAMDS site, Tooele Army Depot South Area, and has demilled approximately 7000 rockets. This machine receives a M55 rocket while still encased in its fiberglass shipping/firing tube, drains the agent fill from it, and using six individually mounted circular saws, cuts the rocket into seven pieces. The munition, which is a nerve gas rocket with either GB or VX agent fill, is shown in figure #6, which also shows the 6 cut locations. The operation is completely automatic and the equipment is housed within an un-manned containment cell, 10 feet in diameter by 24 feet long. Machine motions are all accomplished by hydraulic power supplied from a 20 gpm 1000 psi power unit. The sequence of operation is as follows:

1. The item is placed on an input conveyor and the machine is monitored by appropriate sensors to determine if machine motions are at start condition.

2. If start condition is indicated, the operator (located remotely) initiates"start", which feeds the item, by means of moving conveyors and live rollers, into the punch and drain station of the machine.

3. In the punch and drain station, the item is clamped, punched through the agent cavity and drained of approximately one gallon of liquid agent. Low pressure air is introduced into the agent cavity to assist in agent

removal. A 95% drain is accomplished in 10 seconds. The agent, which has been deposited in a catch tank is then pumped to an adjacent building where it is chemically detoxified.

4. The item is then released and moves approximately 3 feet forward into the saw station where it is clamped by seven cylinder mounted jaws.

5. After clamping, the upper carriage of the machine lowers 11 inches, submerging the rocket in the sodium carbonate tank located beneath the machine.

6. The six milling saws then descend vertically, severing the rocket at the appropriate locations. After all cuts are completed, the saws and the upper carriage return to the raised position.

7. A tray, termed the segregator tray, then enters the machine and positions directly under the cut up item, which is still held by the vise jaws.

8. The vise jaws simultaneously release, depositing the seven pieces in the segregator tray. The tray then retracts into the segregator, completing the cycle.

9. During the next cycle, while the subsequent item is being processed through the RDM machine, the segregator functions, feeding the rocket pieces in a predetermined order to the deactivation furnace.

The six circular saws used on the RDM are Johnson/Kaline milling or cold saws, which use 16" diameter steel triple chip blades and which will cut through the rocket in approximately 45 seconds, while rotating at 22 RPM.

The containment cell, as shown in the previous slide was designed by Ammann and Whitney, NYC , and will contain the blast and frags from the largest item to be processed by this system, which is the 8" chemical projectile, with a 7 lb Comp B_4 burster charge.

MUNITION SHEARING EQUIPMENT

Certain cased munitions are in an explosive quantity catagory which make them prime candidates for degradation prior to thermal demil. These are items containing approximately .1 to 1 pound of HE.

Many items in this H.E. quantity range are physically small and could be easilly processed in a standard deactivation furnace "as-is", except that repeated detonations of this explosive quantity would damage the equipment; consequently the need for degradation equipment.

One such piece of equipment presently under development at the AEO, is the munitions shear machine, shown in figures 7 and 8.

This is a two cavity machine enclosed within a single operational shield. Each cavity is equipped with a munition holding block which shuttles back and forth between the loading station outside the shield and the shear station, inside the shield. The sequence of operation is as follows:

1. The operator loads the munition into the holding block, which is at rest in the load station outside the shield. He then closes the load station door, which starts the automatic cycle.

2. The block immediately moves inward, into the shield and positions the item under a cylinder actuated shear blade.

3. A protective door then closes off the opening through which the block entered the shield.

4. Next the shear (or punch) extends, breaching the munition, then retracts.

5. The block then moves again to its innermost position, where the munition is ejected downward into a gravity chute through which it exits the lower rear of the shield. The means of removal from this point to the furnace is not a part of the machine.

6. The shield door then opens, and the block returns empty to the load station, where it will remain at rest until the operator opens the load door and starts the next cycle.

The munition shear machine motions are all accomplished by hydraulic cylinders, four on each cavity, or a total of eight. Hydraulic power is supplied by a power unit consisting of a double gear pump and fluid reservoir. This unit is located outside the shield and the pumps are each independently capable of delivering 3 GPM @ 1500 psi.

The pilot model shear machine is presently controlled by a programmable sequence controller. This unit receives inputs from built-in limit switches located at the head and rod ends of each of the eight hydraulic cylinders.

A pair of proximity sensors is built into the machine to sense the shearing location. This is to preclude shearing a munition at an incorrect point. Also, the holding block and the load door are so configured that munitions cannot be incorrectly loaded.

Live munition shearing tests have been conducted using the following items:

a. 40 mm M384 cartridge
b. 40mm M406 cartridge
c. M500 fuze w/M21A4 booster
d. M26 grenade w/o fuze
e. M21A4 booster w/adapter

These tests have been run on various quantities of munitions and further sustained runs will be necessary to prove the equipment. Figures 9, 10 and 11 show some typical sheared or punched munition.

Each holding block has a cavity for a particular munition, as shown in figure 12. Change over from one munition to another is accomplished by changing holding blocks and shear/punch blades.

In additon to the aforementioned items, approximately 12000 each unfuzed M42 grenades have been punched on a semi-production set-up of the pilot model shear machine. The munition is shown in figure 13. Production rate on this item is 6-7 items per minute.

The punches used for the M-42 grenade are made from commercial center punches, see figure 14. The final design was arrived at after extensive development work using six different types of blades and a manual shearing fixture (walk-around operation). During these tests, a number of these unfuzed munitions detonated while being penetrated, and for a time it appeared that the job could not be done. However, no detonations have occured since going to the round punch, and since moving the punch location to a point 3/4" from the munition nose, on the side wall. This was also one of the most difficult items to penetrate as the side wall is 1/8" steel, heat treated. The M42 is Comp A_5 filled, and is the only item we have

detonated during punching. We feel that A_5 is our most difficult fill to process from a standpoint of both punching and burning.

Considerable explosive dust is generated by the punching operation and several vacuum devices were used during the tests to relieve this problem. Manual vacuum cleaning was required every hour or so, and further work in this area is planned.

The barricade for the munition shear is a steel cylinder (see previous figure) with elliptical heads on each end, and its axis parallel to the floor. This barricade has been explosively tested several times and in our opinion is satisfactory; however Field Safety Office approval is pending.

An interesting problem encountered during barricade design/test, was the phenomenon of explosive load transmission through machine members.
The steel weldment in which the holding blocks slide, is mounted inside the barricade, but the load area portion extends to the outside. Contact explosions of munitions inside the barricade, caused extremely high stresses to occur in locallized areas of the weldment outside the barricade. In our test, 4 of 6 capscrews holding a plate in position, failed. Theory showed that the plate would have had to be accellerated to approximately 5000 g's to fail these capscrews, and subsequent instrumented tests using accelerometers confirmed the theory.

OTHER MUNITION DEGRADATION PROJECTS

The AEO has been involved in other degradation projects which, due to time considerations, cannot be detailed in this paper , but are worthy of mention.

One of these, the projectile sawing project mentioned in a previous paper, uses a Trennjaeger cold saw to section live conventional projectiles.

A pilot model has been built and various projectiles have been successfully sectioned, ranging in size from 40mm to 175 mm. This equipment is shown in figures 15 and 16.

Shearing tests have been run on metal cased bursters from 105mm, 155mm, and 8" chemical projectiles. Limited tests have demonstrated a high degree of feasibility for shearing these bursters. Approximately 500 items have been sheared without incident. Figure 17 shows a number of sheared bursters.

A Jeffrey rock crusher has been used experimentally to degrade several types of munitions. This is a heavy duty crusher with a single toothed roll, (see figure 18). Unfuzed M-26 grenades were degraded very well using this machine. This unit also did a good job of degrading M21A4 boosters. Degradation of 500 series fuzes with tetryl boosters was largely unsuccessful due to fairly frequent item detonation (about 5%)

SUMMARY

Successful munition degradation can be accomplished in most cases, even though undue force is required. Methods previously thought of as high risk can be employed for degradation provided proper in-depth investigation is done on detonation mechanics of the item in question, and the hardware design made accordingly. Extensive live tests must then be run to confirm the design.

Even with successful design, complete personnel protection must be provided, dictating, in most cases, remote, automatic, barricaded munition degradation machines. In addition to providing personnel protection, due to the high detonation risk, and in the interest of ecomonics, all of our degradation machines have been designed so as to minimize hardware damage, should a detonation occur.

We are probably halfway up the learning curve in regard to design of degradation equipment. A lot has been learned about confinement, friction, explosive exposure areas, point loading etc., as they effect munition detonation. We have successfully degraded, an a production basis, enough munitions to prove feasibility; in fact, we have not yet encountered the item that cannot be degraded by relatively violent methods, although we do not discount this possibility. We feel that the future of munition degrading is expanding and the continuing existance of a huge demil stockpile would seem to confirm this.

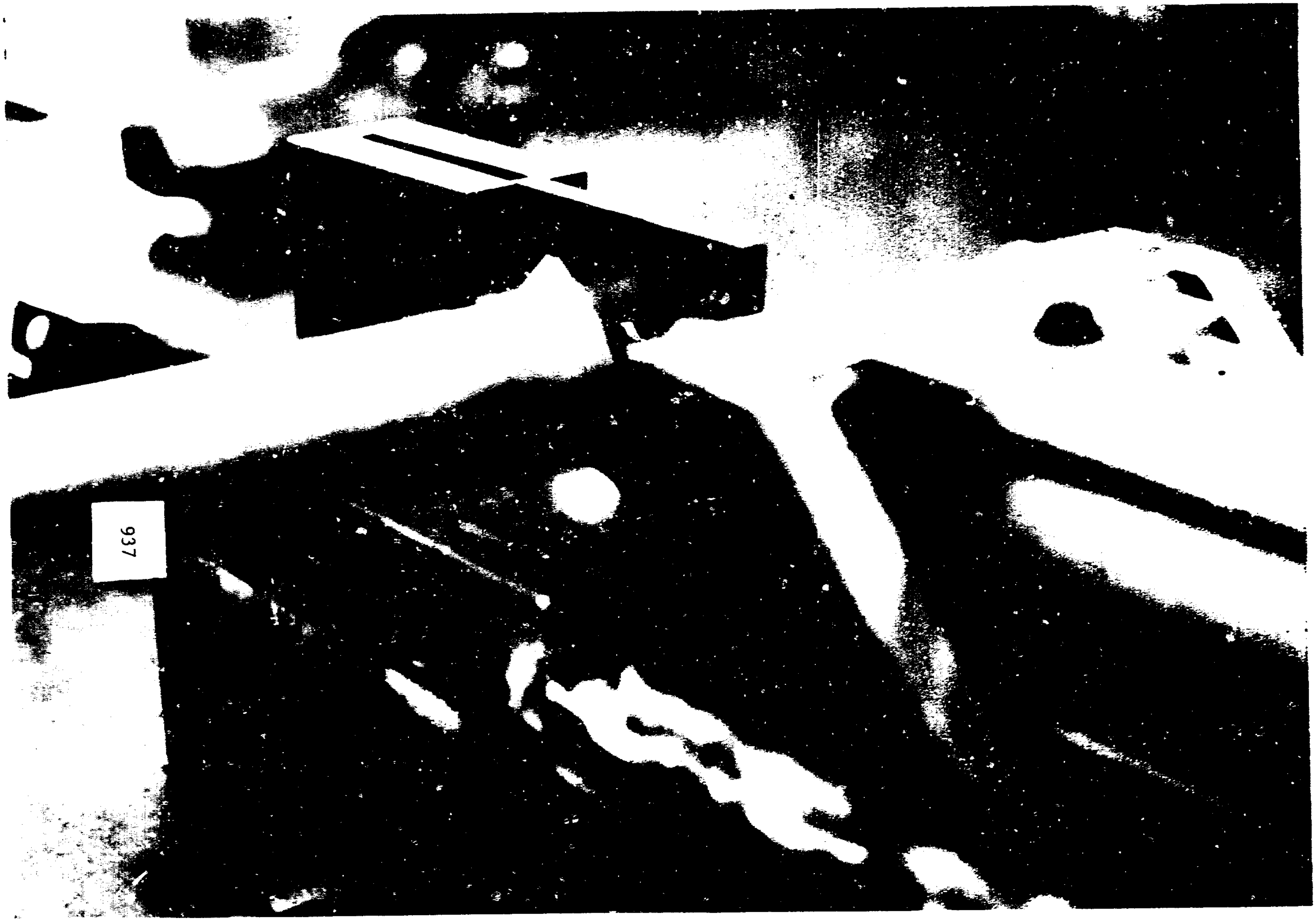
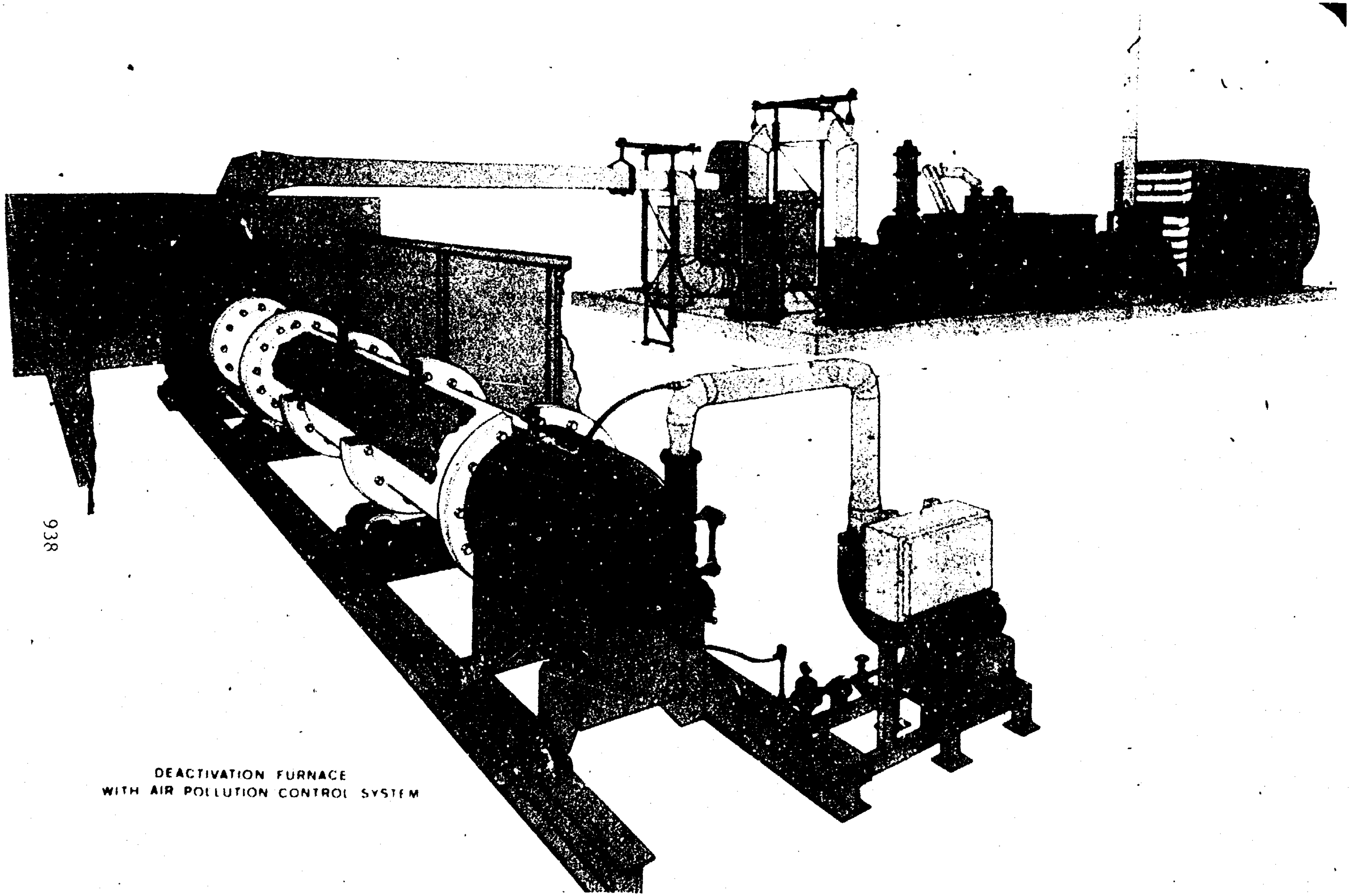
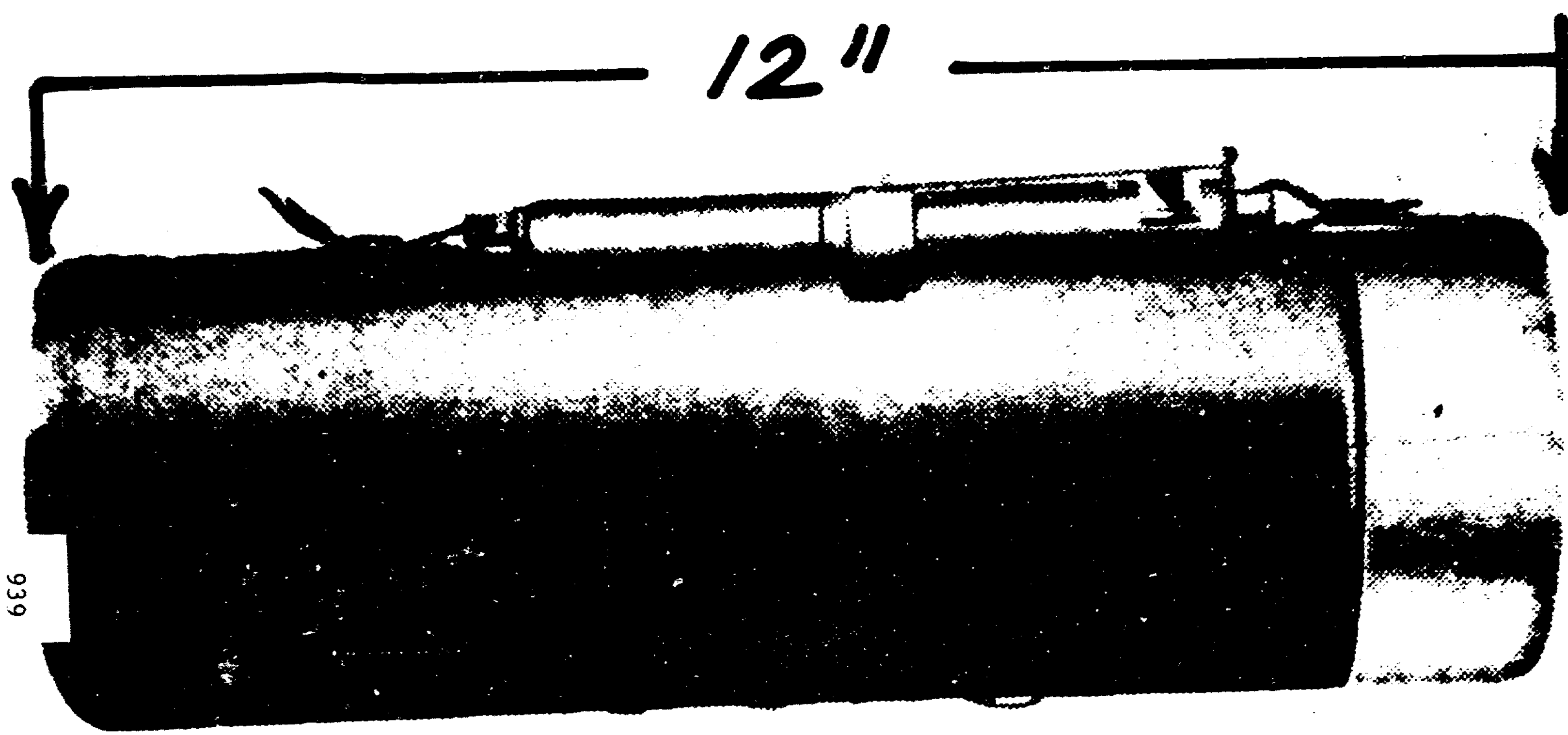


Figure 1



DEACTIVATION FURNACE
WITH AIR POLLUTION CONTROL SYSTEM

Figure-5



M125A1 10-pound GB nonpersistent gas bomb.

Figure 3

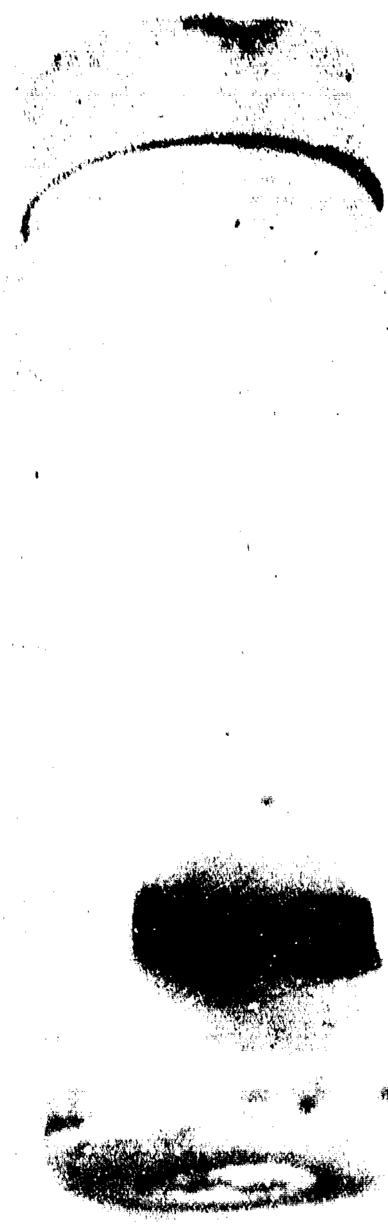
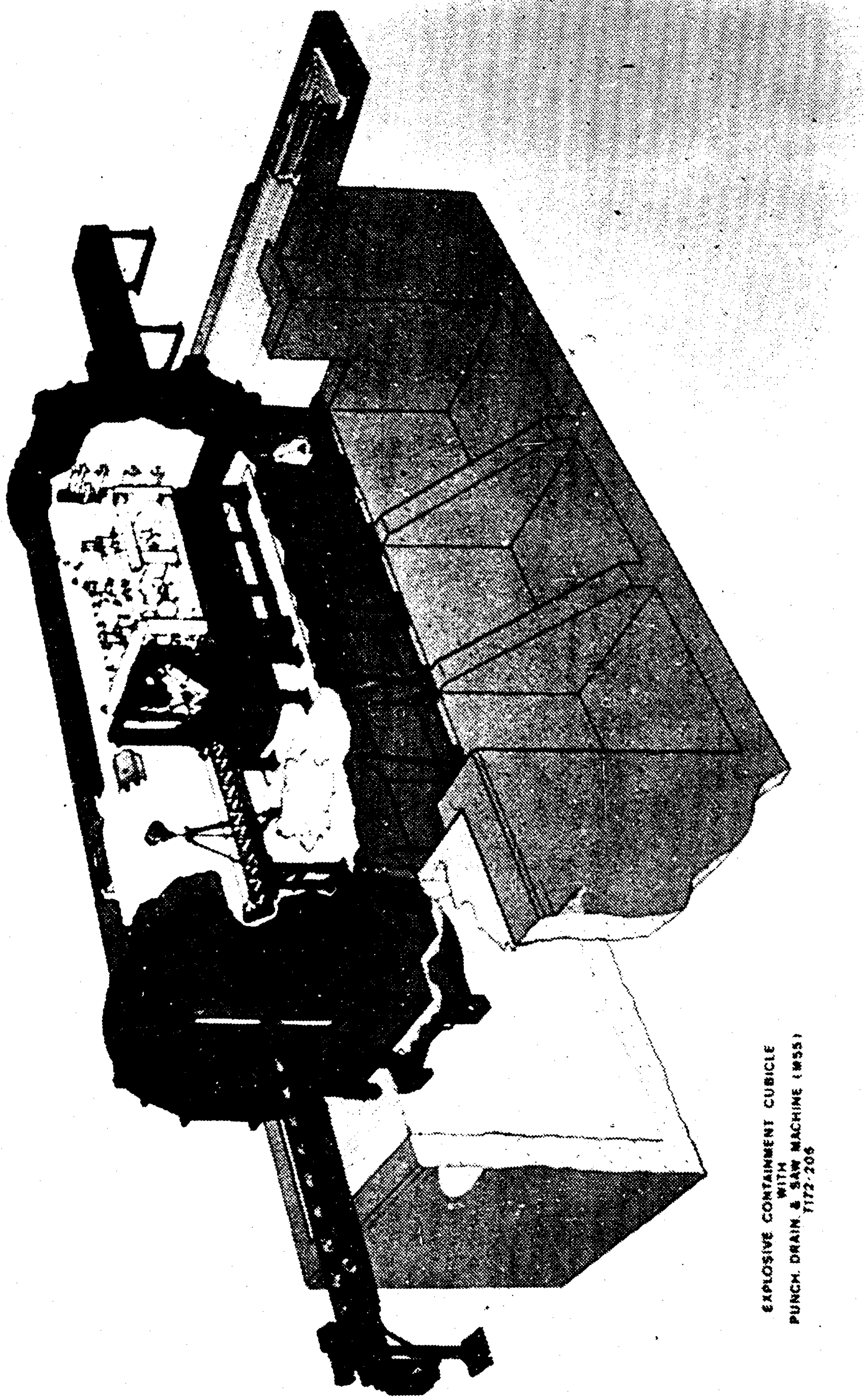


Figure 4



EXPLOSIVE CONTAINMENT CUBICLE
WITH
PUNCH, DRAIN, & SAW MACHINE (M55)
T172-206

Figure 6

Figure 7

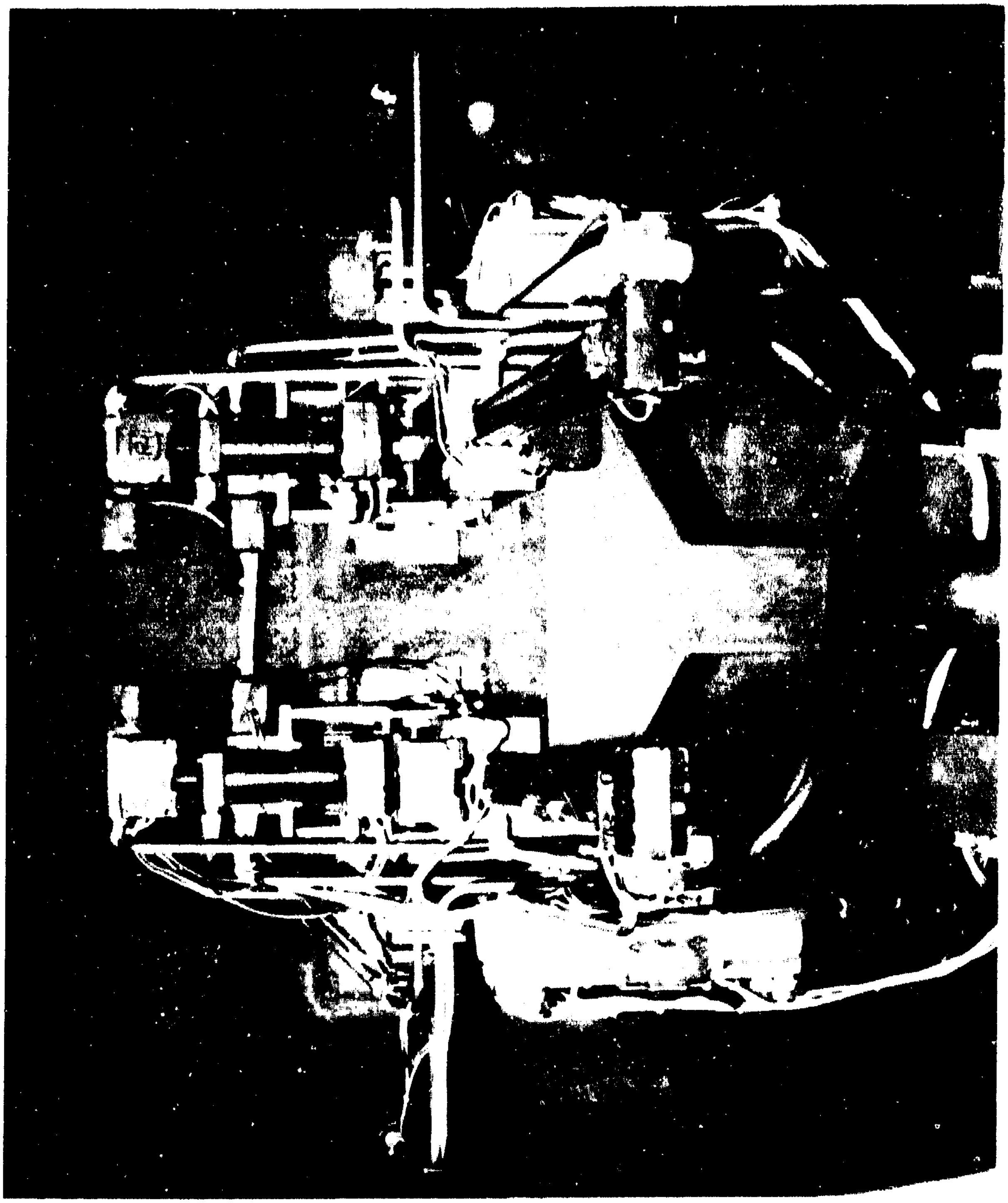


Figure 8

Figure 9

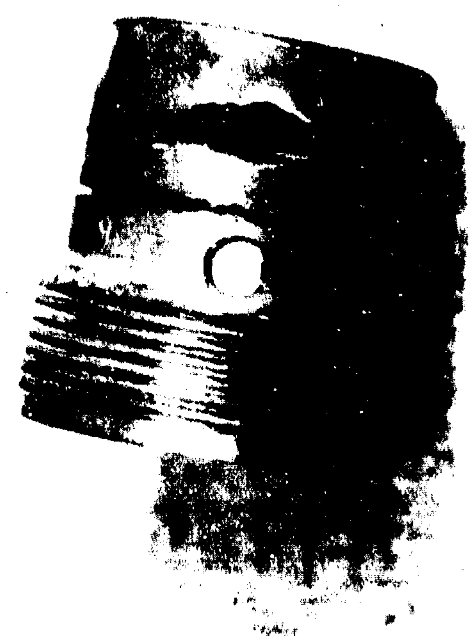


Figure 10

Figure 11

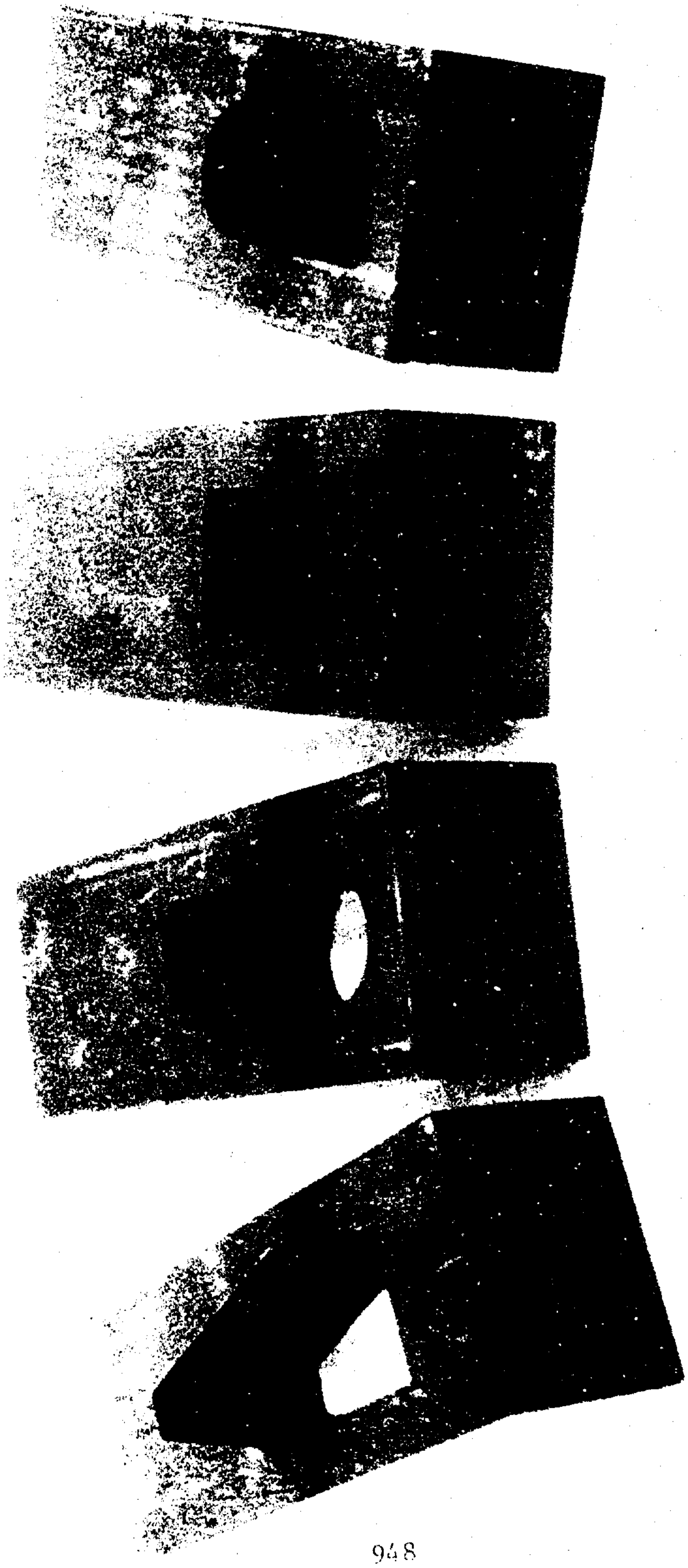


Figure 12

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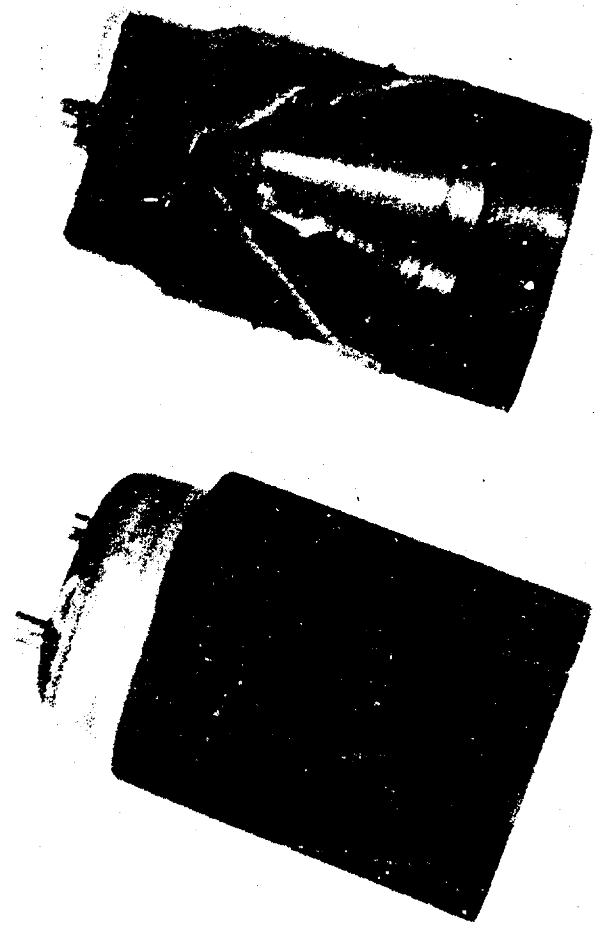

Figure 13

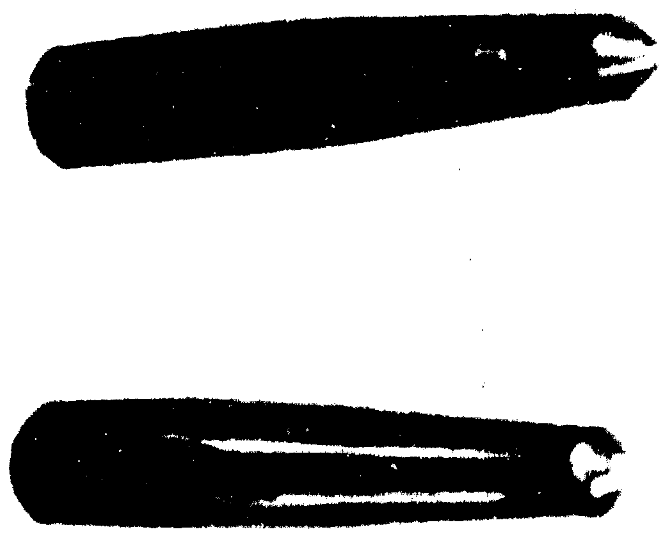

Figure 14

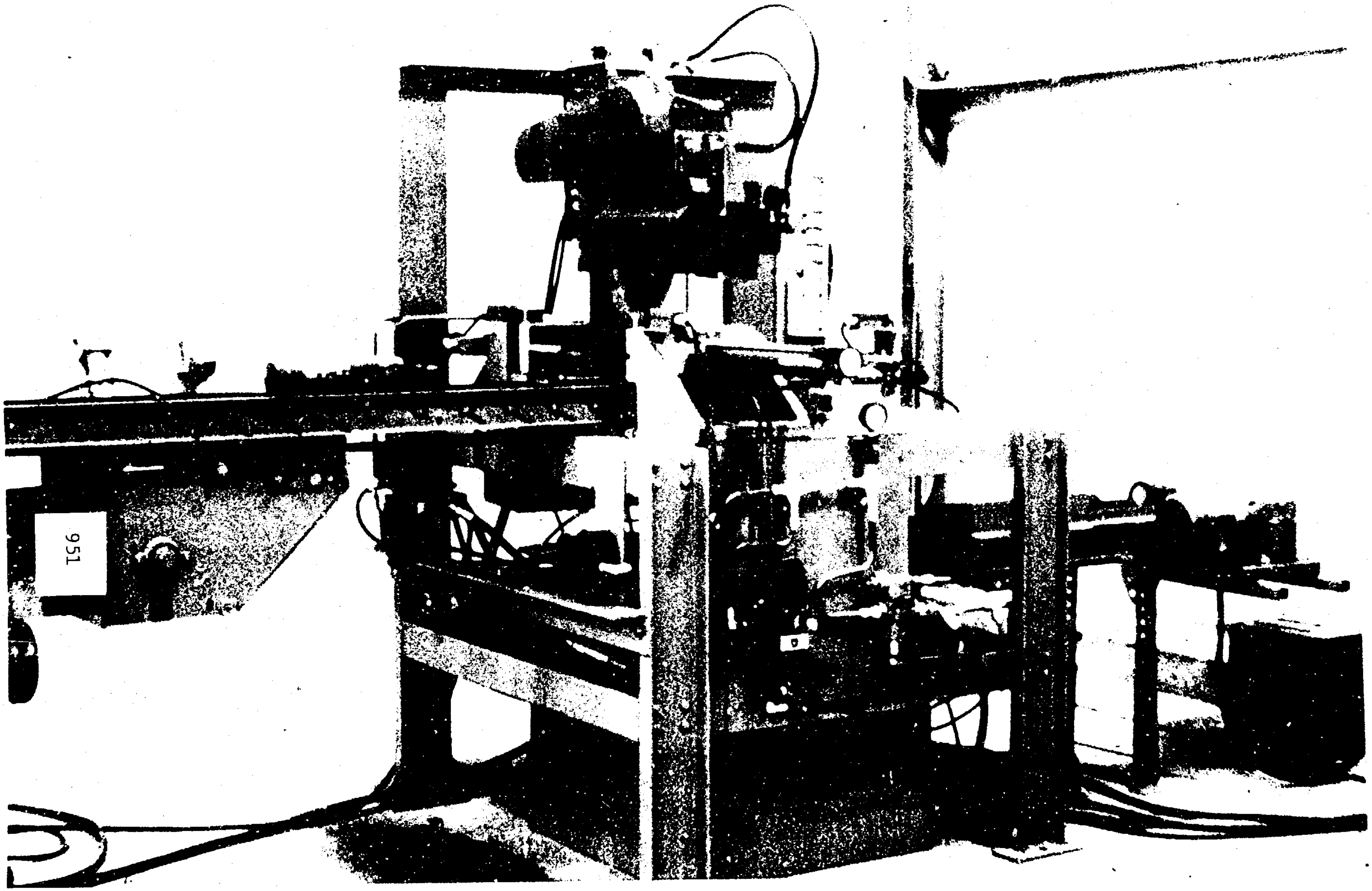

Figure 15

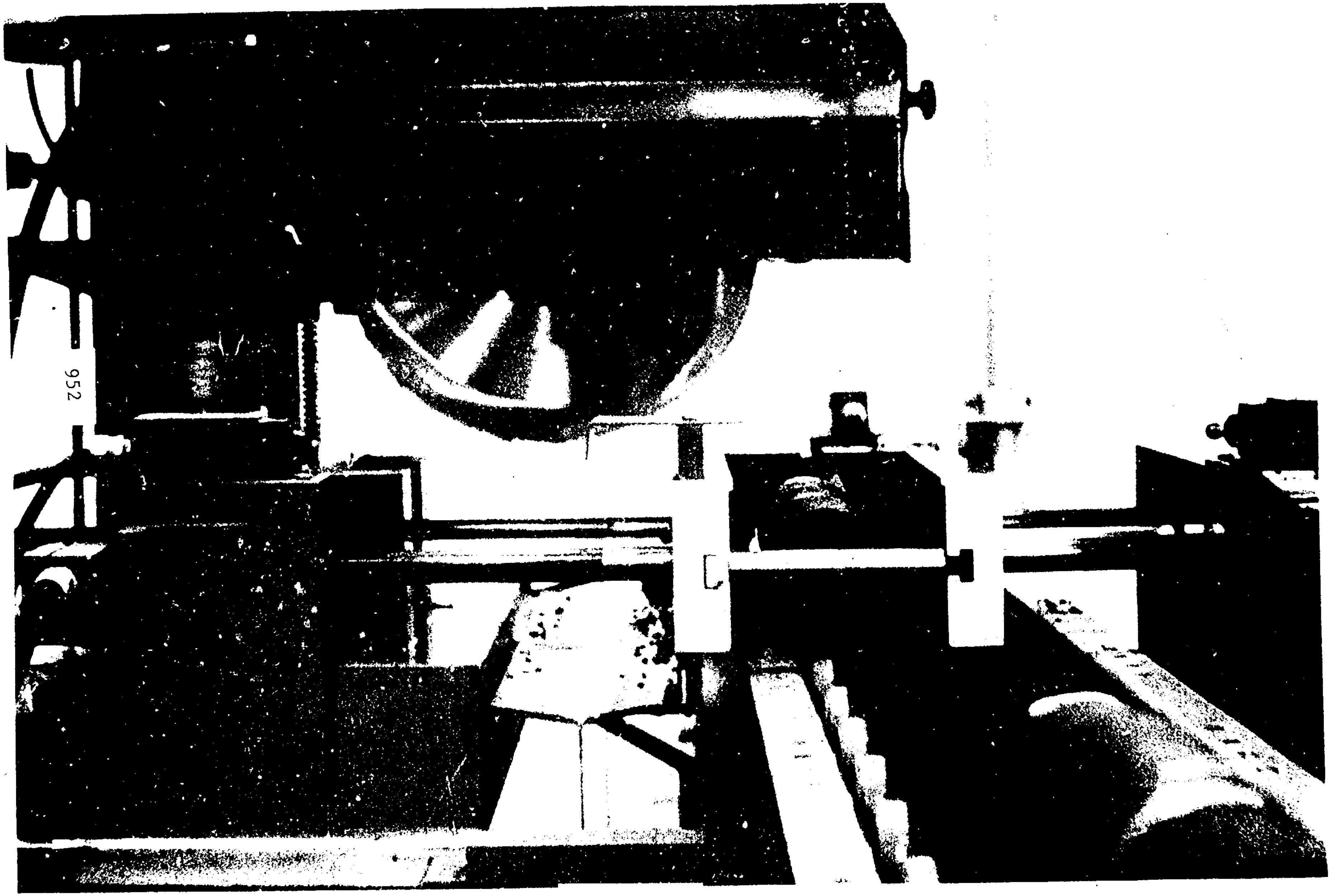

Figure 16

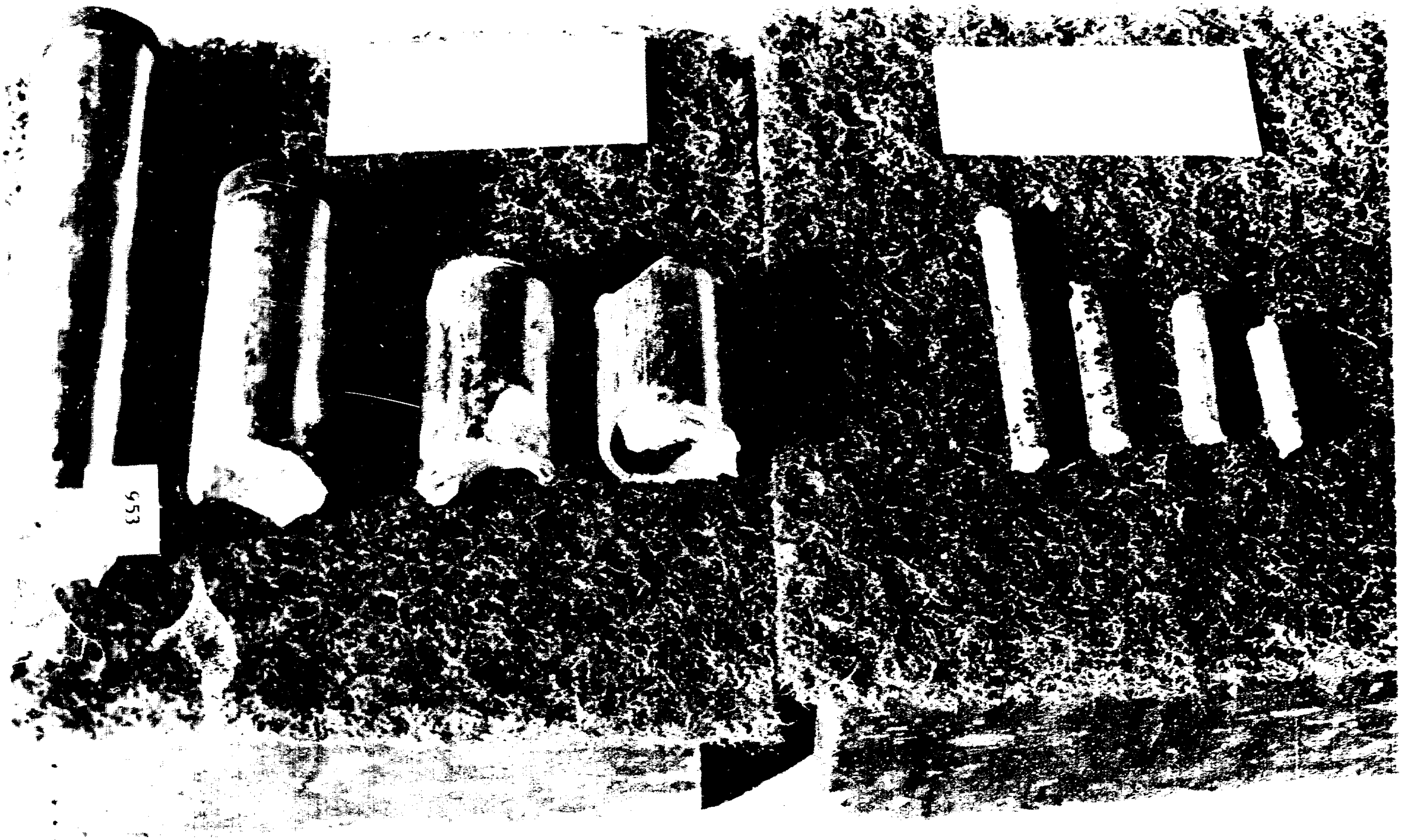

Figure 17

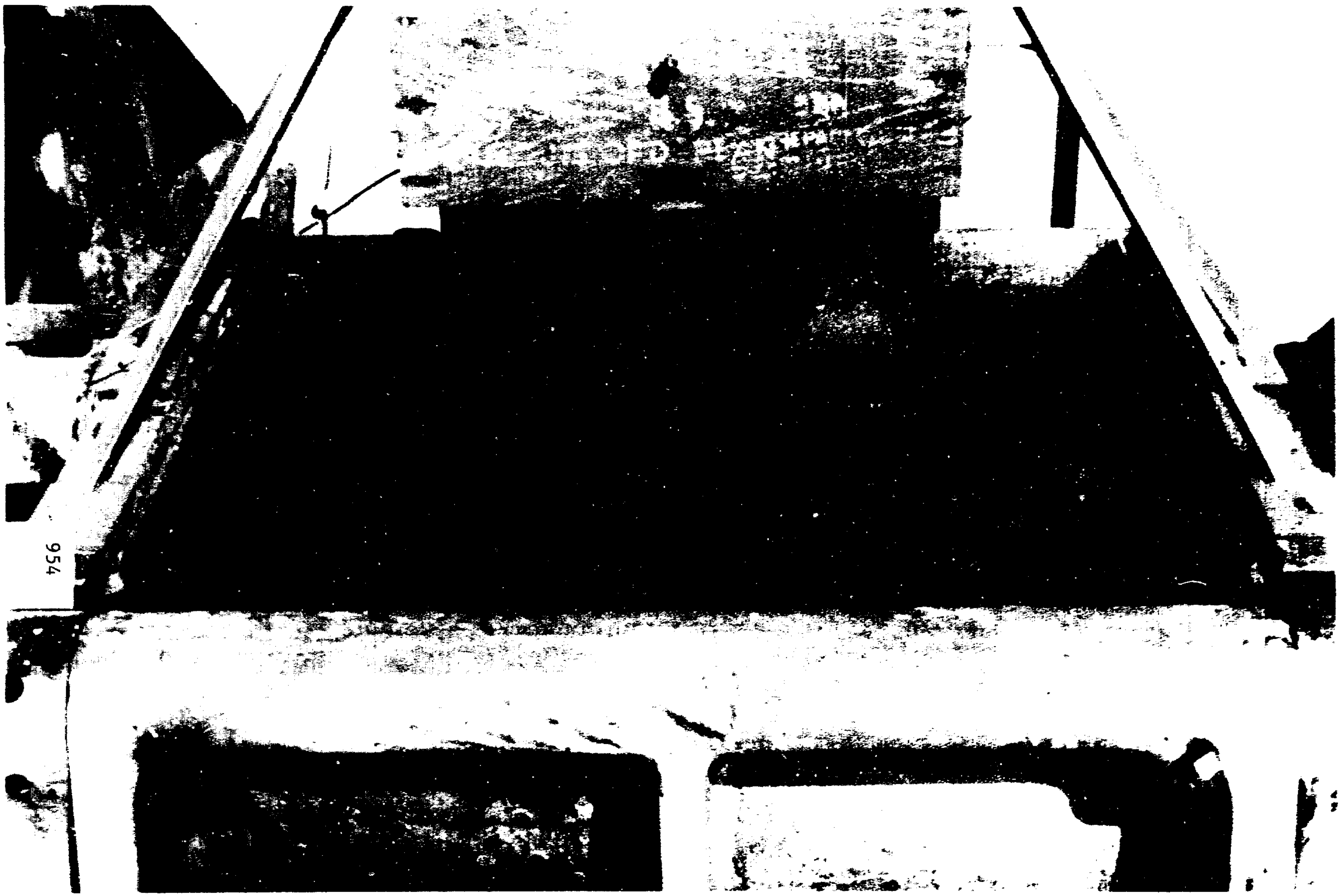

Figure 18

THE EXPLOSIVE WASTE INCINERATOR: AN ALTERNATIVE TO OPEN-BURNING OF WASTE EXPLOSIVES

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Introduction

My presentation today deals with the Explosive Waste Incinerator, a practical alternative to open-burning of waste explosives, propellants and pyrotechnics. This incineration sytem was developed by my office, The Ammunition Equipment Office, at Tooele Army Depot, Utah.

During the manufacture of propellants, explosives and pyrotechnics (PEP), and the loading or filling of end-item munitions at ARRCOM's Army Ammunition Plants (AAP), large quantities of manufacturing or operational wastes are generated that require prompt disposal. These wastes may be off-specification or scrap material. They may be residues from core drilling or turning operations, or spillage or waste from melt-pour operations. Clean-up or wash down will result in material being recovered from catch basins and sumps. The following slides (1 thru 4) illustrate the many configurations of PEP wastes that are generated; e.g., flake, granular, chunks (riser, funnel scrap), cubes and pellets. There may also be "end-item" configurations such as booster assemblies, small arms ammunition, rocket motors and warheads, and artillery primers, fuzes and projectiles.

Historically, the ammo plants have disposed of the bulk PEP wastes by spreading them onto open-burning pads and igniting, with the resultant releases of large volumes of smoke (Slide 5). Generally, the wastes were spread in a layer not exceeding three inches in depth and perhaps up to ten feet wide by several feet long.

These disposal techniques are no longer environmentally acceptable.

The purpose of this presentation is to acquaint you with the currently accepted alternative to open-burning of PEP wastes; specifically, the Explosive Waste Incinerator, acronym EWI (Slide 6).

The EWI is a system, designed to provide a capability for controlled disposal of PEP wastes with containment of effluents from the burning process.

The EWI system, shown in artist's concept is comprised of five major elements: Deactivation Furnace, inside a concrete-walled enclosure; Positive Feed System; Air Pollution Control System; Container Retrieval System; and Equipment Control Panel. Each of these elements will be discussed in detail.

Deactivation Furnace

The basic component of the EWI system is the furnace (Slide 7). The furnace used is an APE 1236 Deactivation Furnace, a long-time standard item in ARRCOM's Ammunition Peculiar Equipment (APE) inventory. The furnace was developed in the early 1950's to demilitarize conventional, explosive-filled end-item munitions at army depots throughout the country and OCONUS. in recent years, use of the furnace has been expanded greatly and there are approximately 25 furnaces currently in use in a variety of conventional and chemical munition demilitarization programs (exclusive of the Explosive Waste Incineration program discussed herein).

The furnace (Slide 8) consists of stationary feed and discharge assemblies, and a cast-steel revolving retort within which the heating and destruction of munitions or explosives occurs.

Bulk explosive wastes, loaded into open-top containers, are injected into the furnace by a positive feed system (described later herein), while assembled or degraded end-item munitions are fed into the furnace on a pantype feed conveyor. Safety interlocks insure that both feed systems are not operational simultaneously. The explosive wastes or munitions are moved through the retort toward an oil-fired flame at the burner (discharge) end of the furnace by means of spiral flights which are an integral part of the retort casting. As the explosive/munitions approach the flame they detonate or burn freely, depending upon the munition configuration and characteristics. An abnormal detonation is contained by the thick retort wall (end sections are 2.25" thick; center sections are 3.25" thick). The spiral flights provide physical separation of quantities of explosives or munitions, discouraging sympathetic propagation of detonations and defeating fragments generated by detonations. Control over quantities of explosive in the furnace at any given time is a function of explosive feed rate, speed of rotation of the retort and temperatures within the retort. Normally, explosives begin burning in the first or second compartment of the retort and are consumed by the fourth or fifth compartment. Metal components of end-item munitions or the bulk explosive containers are discharged from the furnace and the containers are conveyed back to the feed room for eventual reuse.

The furnace is normally operated with No. 2 fuel oil, consumed at rates of 6 gph at low-fire to 23 gph at high-fire. A predetermined reference temperature is established by test as the optimum operating temperature for each type of PEP waste and this temperature is maintained by automatically modulating the oil burner from low to high-fire as the need is indicated by a temperature recorder/controller in the control panel. Typical average fuel consumptions for a given operation range from 9 to 21 gph, for a heat input of from 1.26 million to 2.9 million BTU/hr.

Two thermocouples continuously record furnace temperatures: One thermocouple, inserted at the base of the exhaust stack, provides a

reference temperature to the temperature recorder/controller which maintains the desired operating temperature at this preset reference point; the other thermocouple, inserted immediately above the flame provides a reference temperature at the burner end of the furnace. The controlling reference temperature is set in a range from 300°F to 400°F depending on the items to be burned.

Combustion air is provided by a low-pressure centrifugal blower and by air induced through the metal-parts discharge opening and an annular opening where the retort enters the discharge housing.

An ultra-violet flame sensor is used to detect presence of flame at the burner. Upon flame failure, the UV sensor causes a flame-safeguard unit in the control panel to close the oil valve, shutting off oil flow to the burner, and activating visible and audible alarms at the control panel. A retort motion sensor is used to note rotation of the retort and activates alarms if a failure in the retort drive occurs. A digital readout of retort rotational speed is provided at the control panel.

The furnace is operated within a concrete enclosure designed to contain the effects (blast pressures and fragmentation) of an accidental high-order detonation.

PEP and/or PEP-filled wastes will be delivered in their various containers to the furnace feed building and off-loaded by fork lift. The maximum quantity of explosives permitted in the feed room will be limited to a four-hour working supply. Dry bulk wastes will be manually scooped by plastic or non-sparking scoops from their delivery containers in quantities predetermined by testing and specified in appropriate SOP's but not to exceed five pounds TNT equivalent, in any case. Wet or slurried explosives will be also be loaded into the containers. Vacuum dewatering equipment will be installed at those plants where the manufacturing processes generate wastes with "standing" water. Assembled end-item munitions will generally be hand-placed on the standard pan-type feed conveyor.

Positive Feed System

The Positive Feed System (Slides 9 thru 11) is a specially designed mechanism for injecting containers of explosive into the Deactivation Furnace; and was designed as an accessory to the furnace to be used as an alternate to the standard feed system. For materials such as bulk explosives and propellants, it provides a more rapid and positive furnace feed, reducing the chance of these materials beginning to burn before they are entirely within the confines of the retort. The system eliminates direct line of sight from the point the containers are injected into the furnace to the point behind a concrete barricade where the containers are filled and manually placed into the mechanism. Besides eliminating the chance of explosive propagation to the loading point, the mechanism also positively controls the feed rate to insure that only one container may be placed in the furnace in any one retort compartment. The containers are open-top steel boxes, 5" wide X 5" deep X 12" long, made of 1/8" material.

The operation of the system can probably best be explained by referring to Slide 12. The system consists of three separate submechanisms, the input conveyor, the transfer and the ram. Indicating lights in the control panel signal the location of the explosives container at all times. When the system is ready to feed, the lock on the safety door releases and the door springs open. A container is then placed in the opening and the door is manually closed. The action of closing the door automatically locks the door until the feeding operation has been accomplished and the mechanism is again in the ready position. Closing the door also trips the switch that conveys the container through the concrete barricade to the transfer mechanism. A gap of 3" is maintained between the input conveyor and the transfer to reduce the possibility of a fire propagating from the transfer to the input conveyor.

The transfer mechanism has several unique safety features. When the transfer is in the receive position, a steel plate is directly in front of an opening into the furnace, sealing this opening. When the container is positioned in the transfer, a signal causes the transfer to advance to place the container in alignment with the furnace opening and the ram. The action of moving toward the furnace seals off the opening of the input conveyor by means of a steel plate attached to the transfer. The transfer advances to a halfway position where it awaits a signal from a sensor located on the revolving retort. (At this halfway location, both the input conveyor opening and furnace opening are closed and the container is not exposed to excessive heat). The retort signal insures that one revolution has been completed, placing the previous container one spiral flight away from the receiving space in the retort opening.

Upon receipt of the retort signal, the transfer proceeds to line up the container with the furnace opening. The container is immediately accelerated by the ram and it slides through the furnace opening to alight within the retort. After the ram returns, the transfer returns to a receive position. The ram action is rapid with the explosive container injection taking about one second. The process is then ready to be repeated. Should a malfunction in the ram occur while the container is in line with the furnace opening, the transfer will automatically return to the halfway point within four seconds and an alarm will sound. This precludes any chance of exposing the containers to heat outside of the retort.

By use of controlled speed actuators (on input conveyor and ram) spillage of explosive will be reduced to a minimum or eliminated with the established explosive feed rates and container sizes.

By means of the retort position cam and limit switch, the Positive Feed System is limited to injecting only one container into the furnace per compartment of the retort (i.e. only one container can be injected into the furnace each revolution of the retort).

Air Pollution Control System

The Air Pollution Control System (depicted in the flow diagram, Slide 13) consists of an indirect, forced-air cooler which will cool entering gases from a maximum of 1000°F down to 250°F; a centrifugal dust collector (cyclone) that achieves some particulate removal but is used primarily for spark arrest; a baghouse for final particulate cleansing; and a thirty foot exhaust stack.

Exhaust gases exit the furnace at a maximum rate of 3600 scfm @ 500°F or 1,500 scfm @ 1100°F and are cooled, if necessary, by mixing with ambient air introduced through an automatically modulated cooling air damper controlled by a thermocouple installed immediately preceding the cooler. The gases proceed through the cooler, passing over flattened heat-exchange tubes through which ambient cooling air is blown and then exhausted in the form of recoverable heated air. The furnace exhaust gases then leave the cooler at approximately 250°F. A thermocouple immediately preceding the baghouse insures that temperatures entering the baghouse do not exceed 250°F by signalling a temperature switch to close an in-line damper ahead of the baghouse, and shut off the induced draft fan if the temperatures start to exceed 250°F. Some particulate will be deposited on the heat-exchange tubes and is removed by chains scraping across the tubes. The particulate is then moved via a screw conveyor to a double-dump discharge valve for collection.

The cooled exhaust gases pass through a cyclone collector for some further particulate removal and for spark-arrest.

The gases (maximum 4800 acfm @ 250°F) are then directed through a baghouse for final particulate cleansing. The baghouse is a 144 bag unit (bags are 4.5" dia. X 8'-0" long; 1356 ft^2 total filter area), providing a 3.5 air to cloth ratio. The bag material is nomex felt. Nomex is a relatively high temperature resistant nylon fiber (450°F maximum operating temperature) with reasonably good acid resistant characteristics. The bags are periodically cleaned by introducing a jet-pulse of air at the top of

each bag causing a momentary reverse flow through the bag forcing the collected dusts into a hopper at the bottom of the baghouse. The collected dusts are continuously discharged through a double dump discharge valve.

The cleaned gases are finally drawn through the induced-draft fan and exhausted out the thirty foot exhaust stack. Sampling ports are provided in the horizontal duct (at ground level) between the baghouse and fan.

Container Retrieval System

A Container Retrieval System (depicted in Slide 14 showing overall equipment layout) picks up the explosives containers from the discharge end of the furnace and returns them to a collection point outside the feed room. As the containers are conveyed toward the feed room, they pass through a shrouded section of conveyor where they are cooled by ambient air blown through the shroud.

Equipment Control Panel

The equipment components described herein are all controlled from and by the Equipment Control Panel (Slide 15) which conforms to a Class II, Group E, Division I hazardous location classification by being air-purged and pressurized.

Located outside of the feed room is a purge blower enclosure (repeat Slide 14) which contains a purge fan and associated interlocking circuitry. This circuitry begins with a stop-start switch located in the enclosure cover which is used to pick up and drop out the purge fan. The fan is rated at 250 CFM. In the discharge air stream of the fan is a flow switch which is rated to drop out at an air velocity of 630 ft/min. (The fan output velocity at 200 CFM is 2100 ft/min.). After the fan is switched on and the air velocity reaches 750 ft/min., the flow switch closes which in turn energizes a timer. A purging process continues until the time set on the timer, 120 seconds, has passed. The time allows 10 case volume changes of

air to be put into the enclosure before the timer closes. The timer closes and picks up a 3-phase power contactor which applies the power to the main control panel distribution center.

The main control enclosure (NEMA 12) is located inside the feed room thru the wall from the purge fan enclosure. The two are connected via a 4-inch air duct. The main control enclosure contains the motor starters, push button stations, indicating lights and instrumentation necessary to operate the EWI facility.

The main panel also contains an internal air pressure indicating gauge to show the inside pressure, in inches of water, at all times. This feature allows the operator a quick visual check if needed.

If the main enclosure is opened for some reason, after the initial purge, the fan will continue to run and the power contactor remains energized since it is a greater hazard to shut down than to lose purge pressure; however, the system alarm will sound and a light will illuminate indicating the console door is not shut.

Testing

Extensive testing was done to demonstrate the feasibility of burning bulk PEP in the furnace. Several types of explosives and propellants were burned to obtain such operational data as feed rates, furnace temperatures, emission rates and furnace operating parameters. Feed rates up to 600 lb/hr were achieved. This feed rate represents the maximum design rate. Particulate emission data were obtained for use in design of the air pollution control system.

Of particular significance were tests conducted to determine maximum quantities of explosive that if involved in an unanticipated detonation would not constitute a safety hazard to operating personnel, either from blast overpressures or from fragments. An old furnace at Tooele was used

for these tests (Slide 16). Explosive charges, beginning at 0.5 lb TNT equivalent and increasing to 7.23 lbs, were detonated in the furnace at a location representative of a worst case situation. No equipment damage was incurred up to and including 0.75 lb; however, beyond that equipment damage became greater, necessitating extensive repairs between tests. The tests were terminated at 7.23 lbs.

Blast pressure transducers were positioned at several places representative of potential operator locations. Pressure transducers were also installed in the concrete barricade walls at either end of the furnace to obtain pressure design data for new enclosures. High-speed film was used to observe blast and fragment phenomena.

The tests showed that a detonation involving up to 7.23 lb TNT equivalent would cause extensive damage to the equipment but would not cause peak positive incident overpressures at operator locations of 2.3 psi, maximum allowable for operator exposure. Fragmentation outside the furnace enclosure was minimal, indicating some minor design improvements to preclude any further problems. Design parameters established prior to these tests specified that no more than 5.0 lb TNT equivalent would be injected into each furnace retort compartment; therefore, tests were also conducted to determine if propagation would occur between explosive charges placed in compartments separated by spiral flights within the retort. The tests failed to produce any propagation even though explosive charges in compartments adjacent to a donor charge were displaced.

The data from these tests were provided to the Hunstville Division, Corps of Engineers for design of the concrete protective walls enclosing the furnace.

A very detailed Hazard and Safety Analysis, (including a Fault Tree Analysis, Slide 17) of the entire EWI System was accomplished by Tooele Safety Office. The safety analysis, along with the final report of the

tests described earlier, and a comprehensive Design Analysis of the EWI System, were forwarded to DARCOM Field Safety Activity for their review and approval; and the Dept of Defense Explosive Safety Board (DDESB) endorsed the DARCOM Safety approval.

Summary

In summary, the EWI (Slide 6) represents a practical alternative to open burning of explosive wastes. The first system is scheduled to be completed this month at Louisiana Army Ammunition Plant. Construction is scheduled to commence next month on systems at Kansas and Iowa AAP. Installed costs for an EWI system are currently approximately \$565,000 for equipment and \$450,000-500,000 for "brick and mortar" supporting facilities.

Our efforts to develop an incineration alternative to open-burning were initiated at the request of ARRCOM's Environmental Office. Final designs were accomplished under the auspices of the Army Pollution Abatement Program (APAP), directed by the Huntsville Division, Corps of Engineers.

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2. D.B. Hill, Design Analysis for Explosive Waste Incinerator; AEO Report No. 19-79, June 1979

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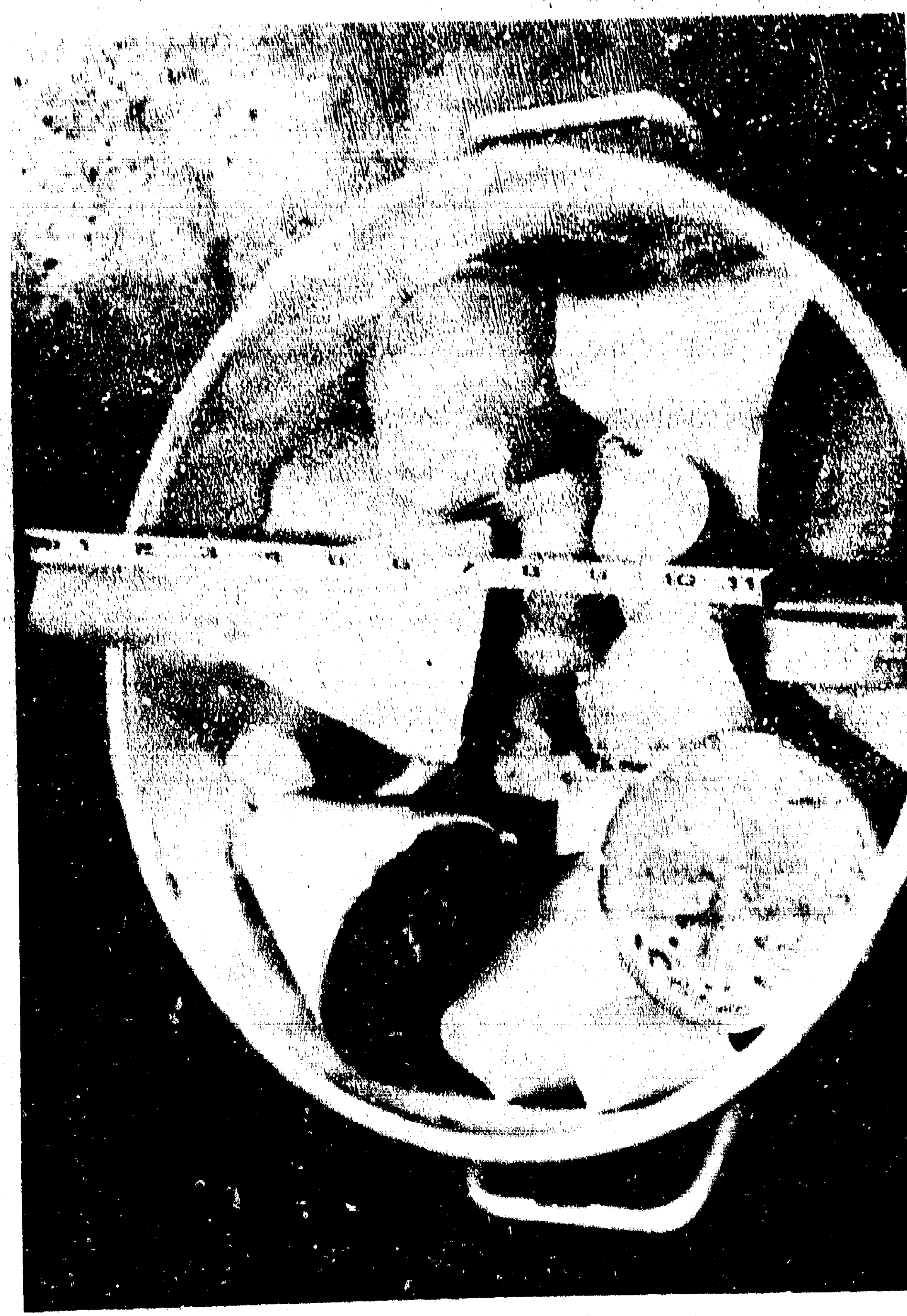
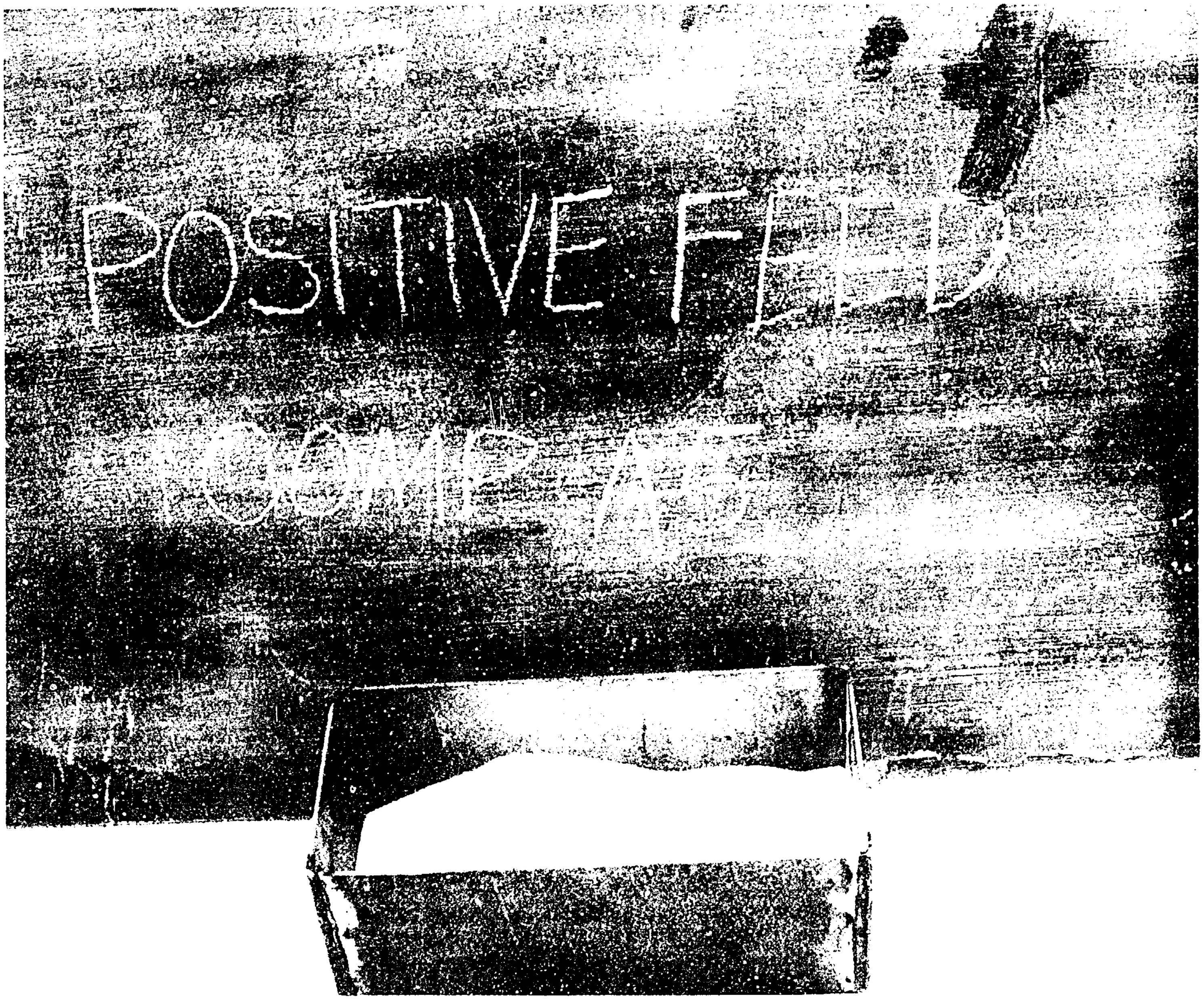


SLIDE 1

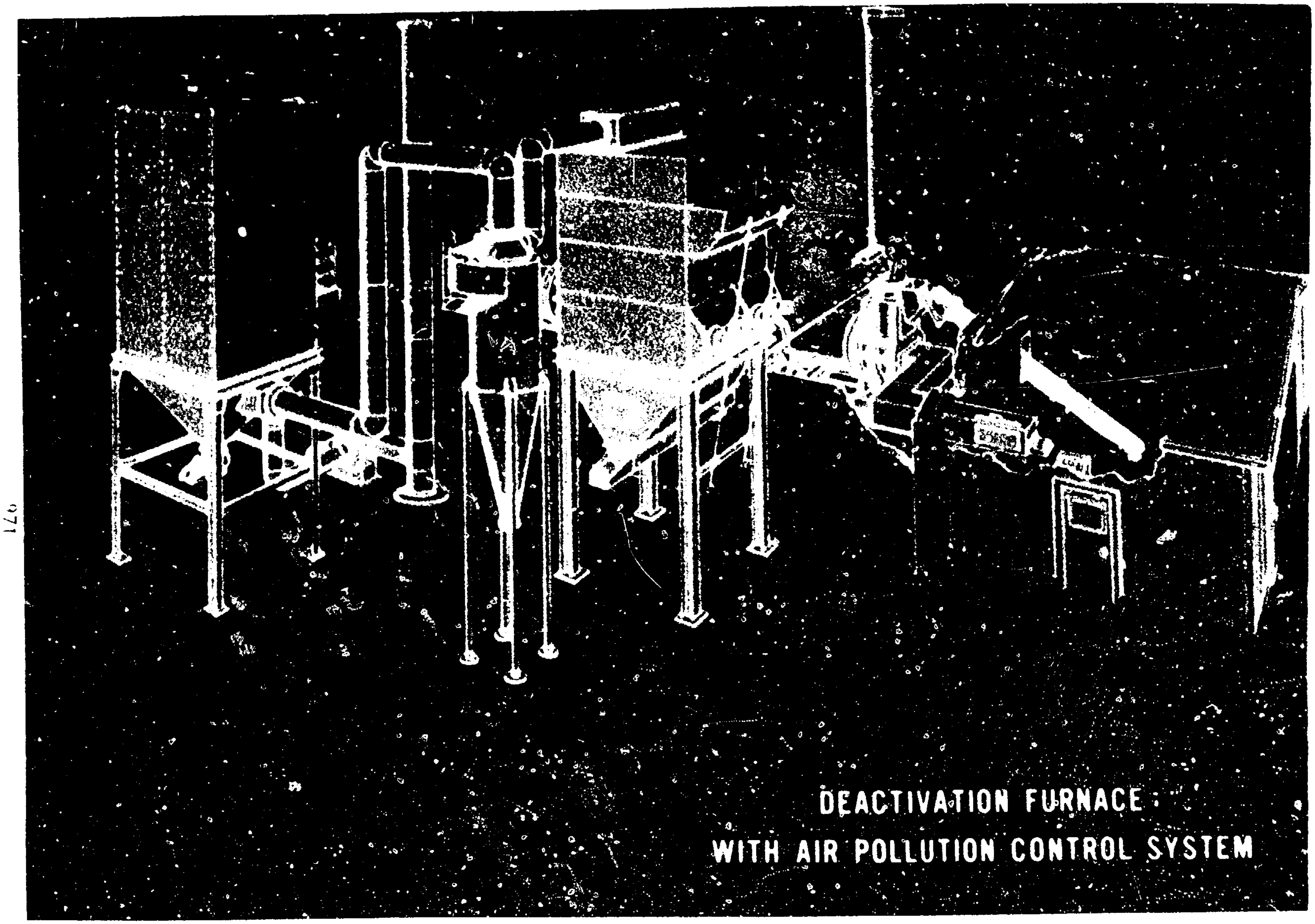
SLIDE 2



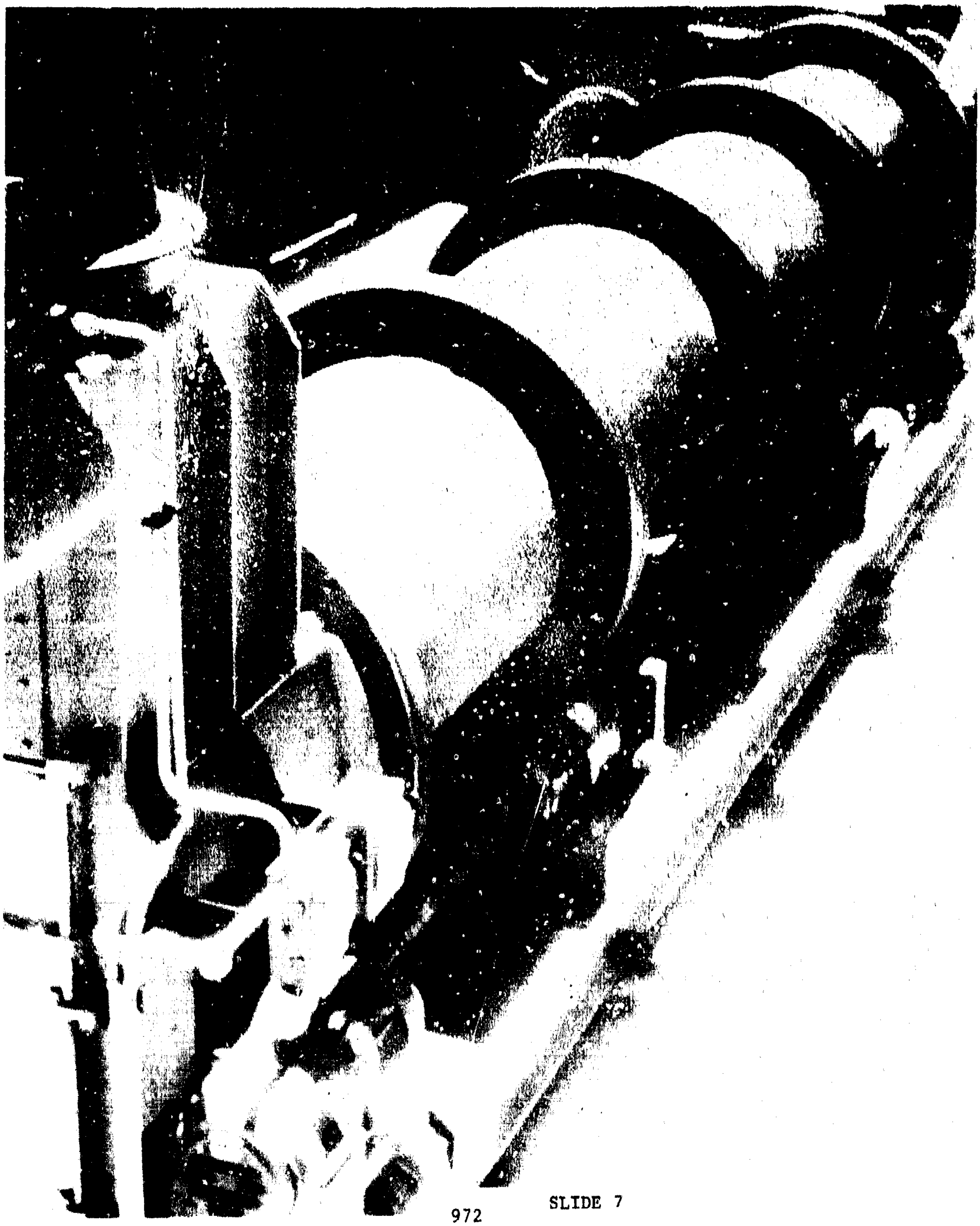
SLIDE 3

SLIDE 4

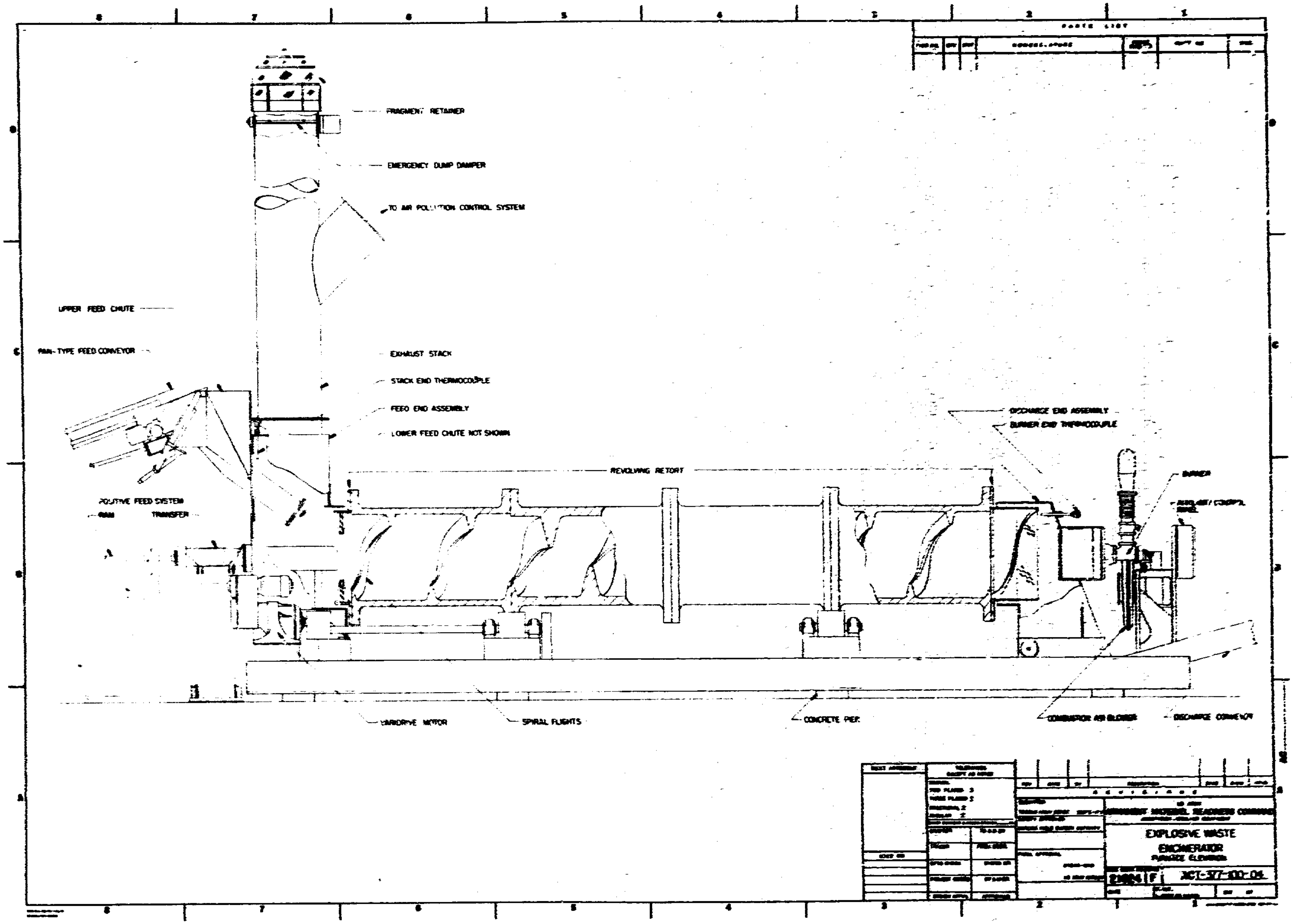
SLIDE 5



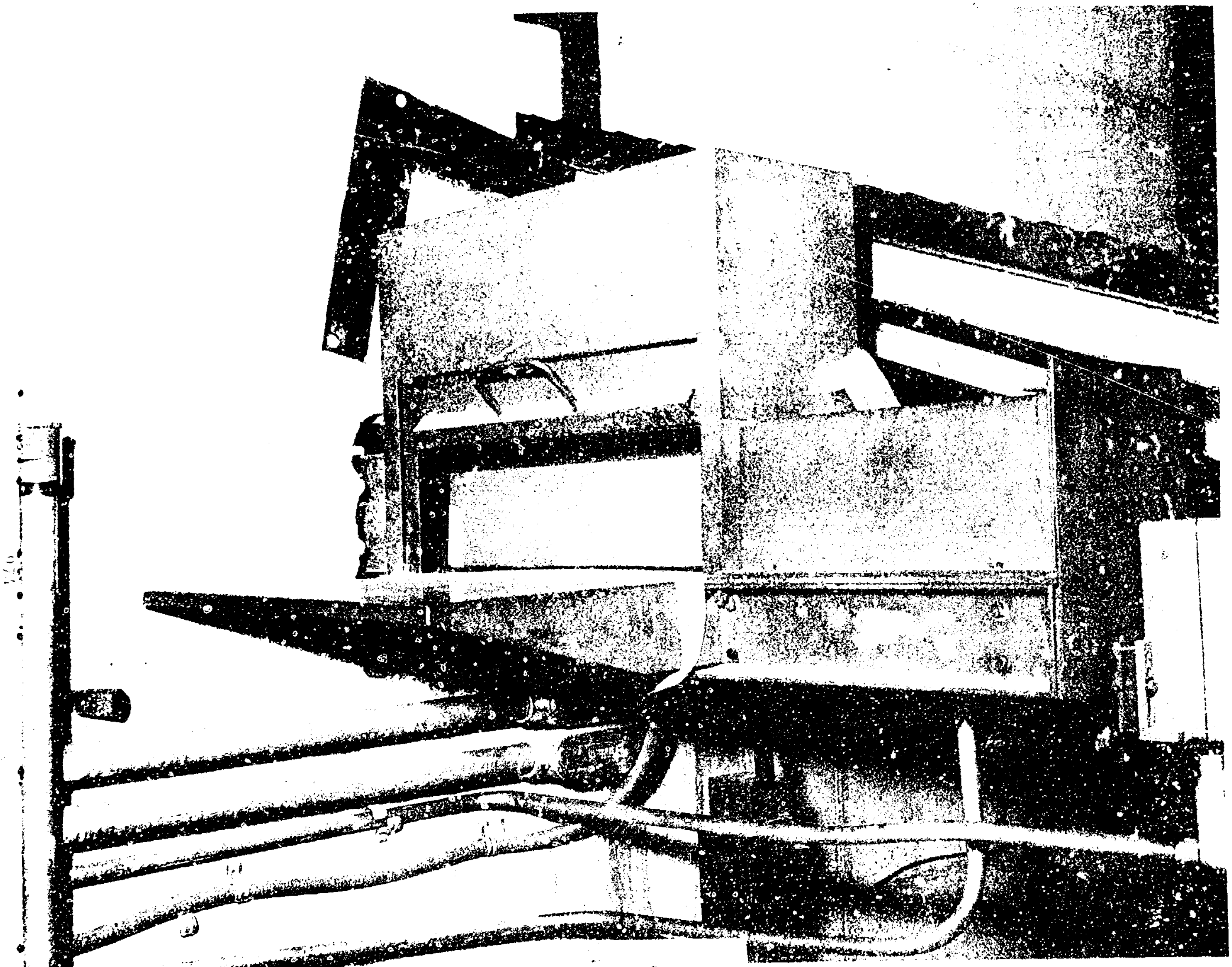
SLIDE 6



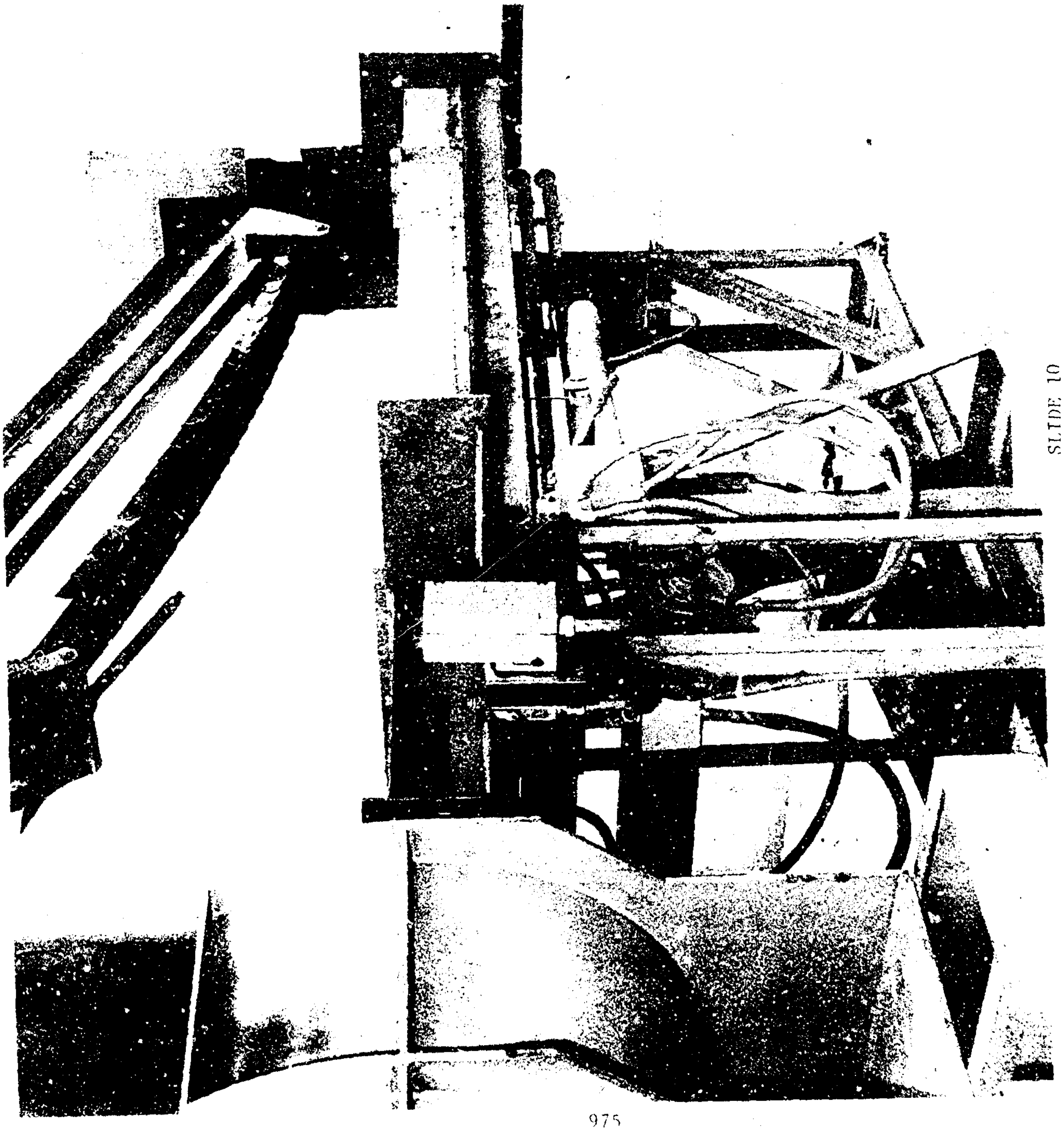
SLIDE 7


PARTS LIST
FRAGMENT RETAINER
EMERGENCY DUMP DAMPER
TO AIR POLLUTION CONTROL SYSTEM
UPPER FEED CHUTE
PAN-TYPE FEED CONVEYOR
EXHAUST STACK
STACK END THERMOCOUPLE
FEED END ASSEMBLY
LOWER FEED CHUTE NOT SHOWN
POSITIVE FEED SYSTEM
RAM
TRANSFER
REVOLVING RETORT
DISCHARGE END ASSEMBLY
BURNER END THERMOCOUPLE
BURNER
VARIDRIVE MOTOR
SPIRAL FLIGHTS
CONCRETE PIER
COMBUSTION AIR BLOWER
DISCHARGE CONVEYOR
EXPLOSIVE WASTE
INCINERATOR
FURNACE ELEVATION

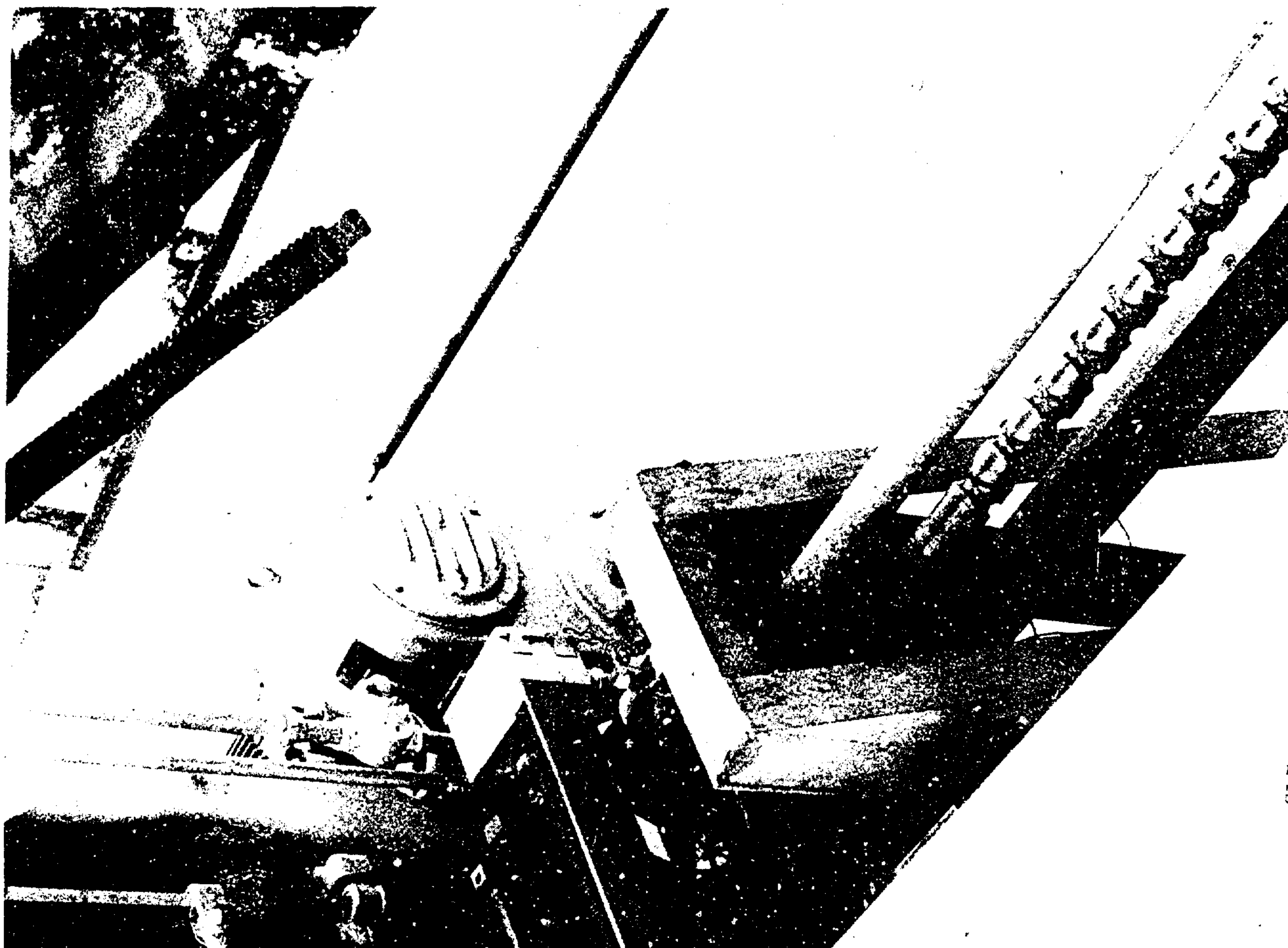
SLIDE 8



SLIDE 9



SLIDE 10



SLIDE 11

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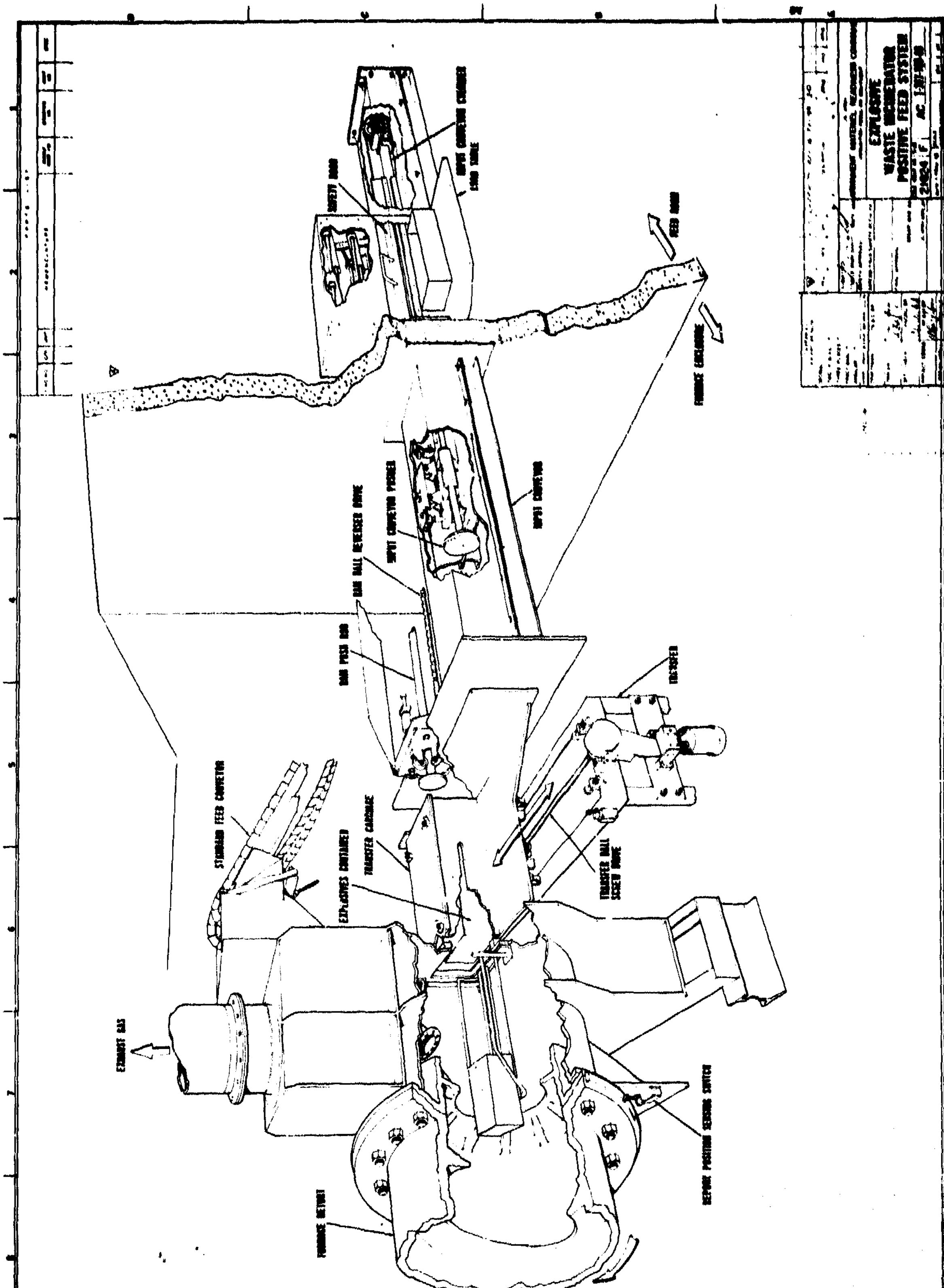
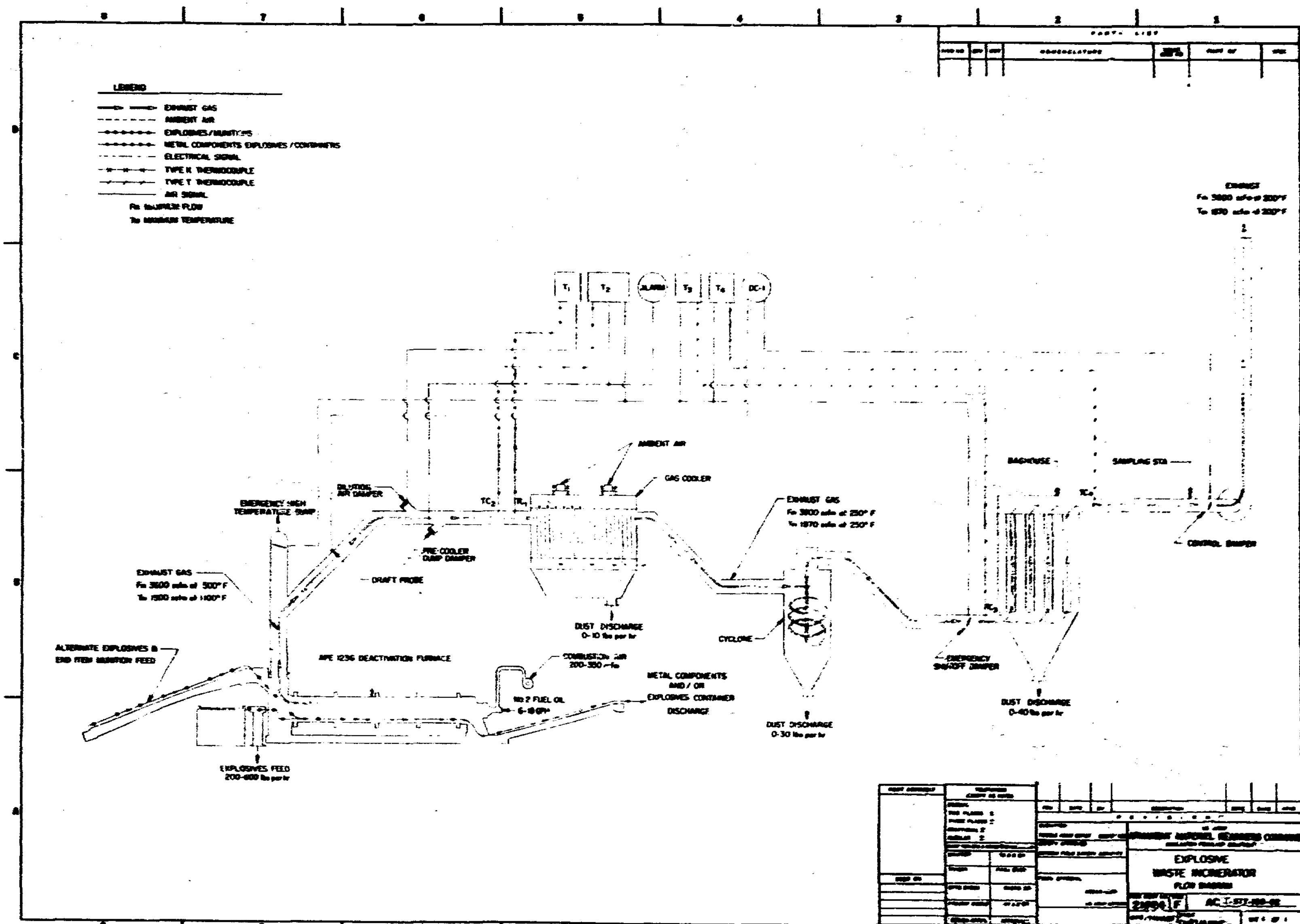
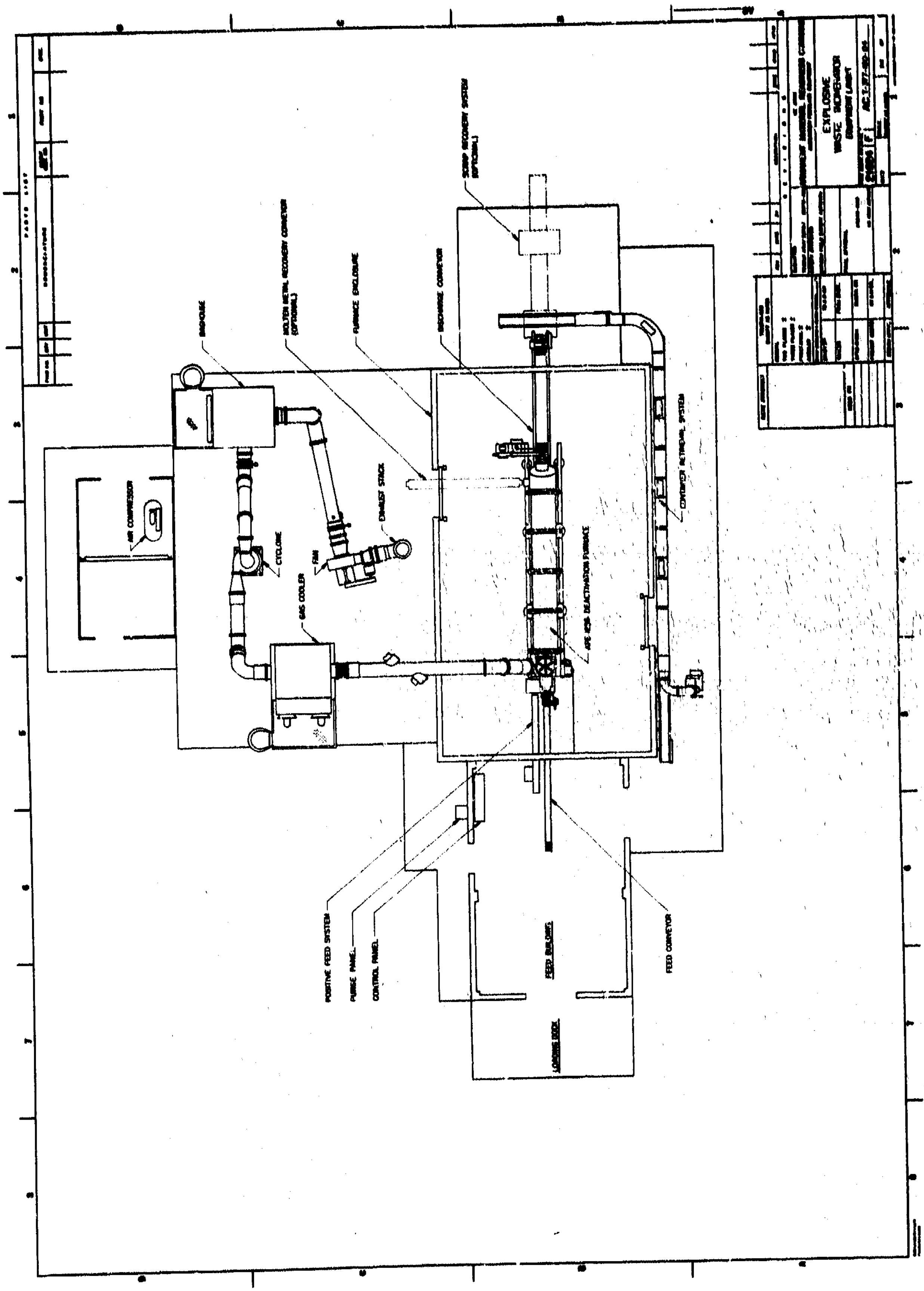


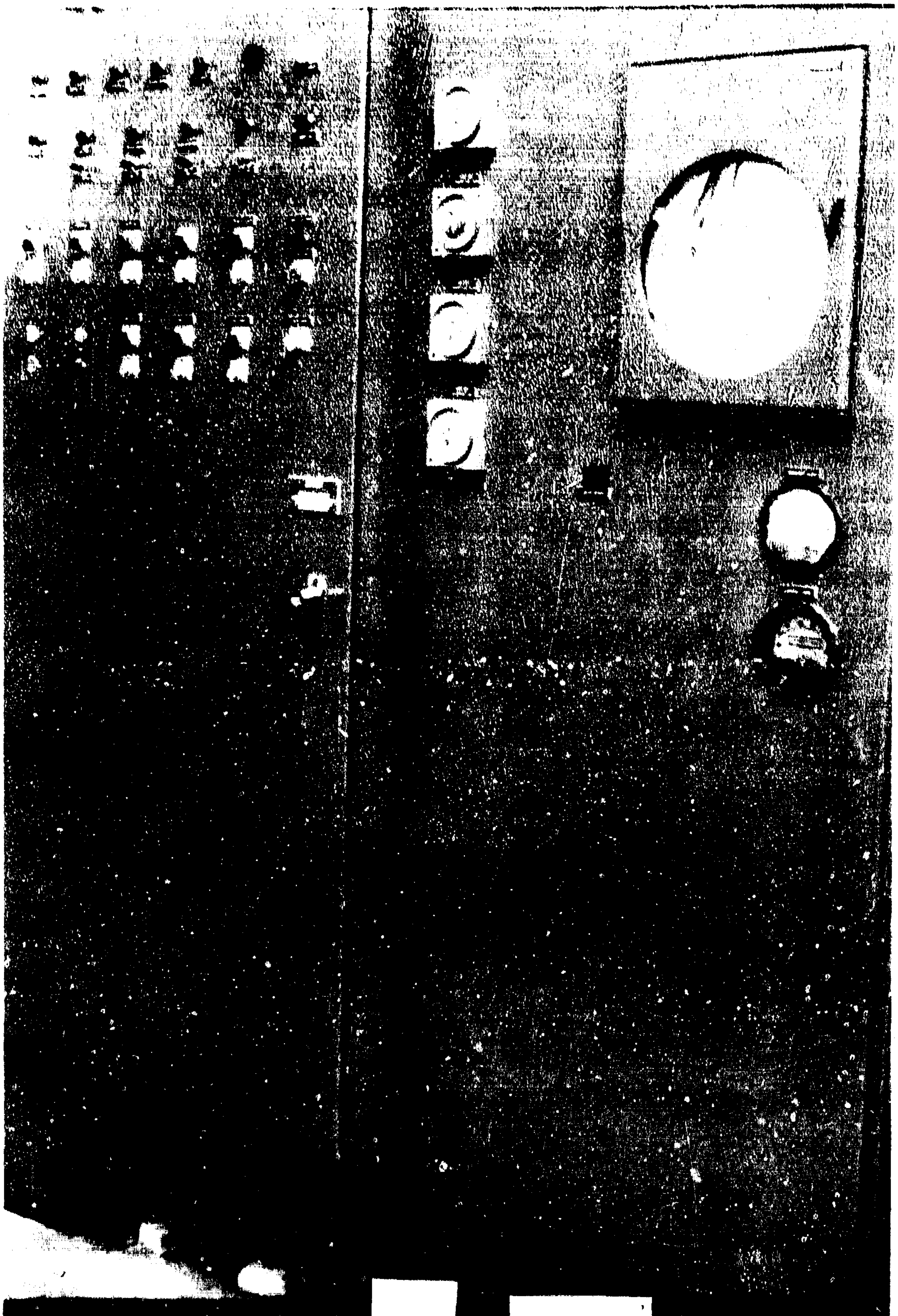
SLIDE 12


LEGEND
EXHAUST GAS
AMBIENT AIR
EXPLOSIVES/MUNITIONS
METAL COMPONENTS EXPLOSIVES / CONTAINERS
ELECTRICAL SIGNAL
TYPE K THERMOCOUPLE
TYPE T THERMOCOUPLE
AIR SIGNAL
Fm MAXIMUM FLOW
Tm MAXIMUM TEMPERATURE
EXHAUST
Fm 3800 scfm at 300°F
Tm 1870 scfm at 300°F
AMBIENT AIR
GAS COOLER
BAGHOUSE
SAMPLING STA
CONTROL DAMPER
DILUTION AIR DAMPER
EMERGENCY HIGH TEMPERATURE DUMP
PRE-COOLER DUMP DAMPER
DRAFT PROBE
EXHAUST GAS
Fm 3800 scfm at 500°F
Tm 1900 scfm at 1100°F
EXHAUST GAS
Fm 3800 scfm at 250°F
Tm 1870 scfm at 250°F
ALTERNATE EXPLOSIVES & END ITEM MUNITION FEED
APE 1236 DEACTIVATION FURNACE
DUST DISCHARGE
0-10 lbs per hr
CYCLONE
COMBUSTION AIR
200-350
No 2 FUEL OIL
6-18 GPH
METAL COMPONENTS AND / OR EXPLOSIVES CONTAINER DISCHARGE
DUST DISCHARGE
0-30 lbs per hr
EMERGENCY SHUTOFF DAMPER
DUST DISCHARGE
0-40 lbs per hr
EXPLOSIVES FEED
200-600 lbs per hr
EXPLOSIVE
WASTE INCINERATOR
FLOW DIAGRAM
AC-I-577-100-02

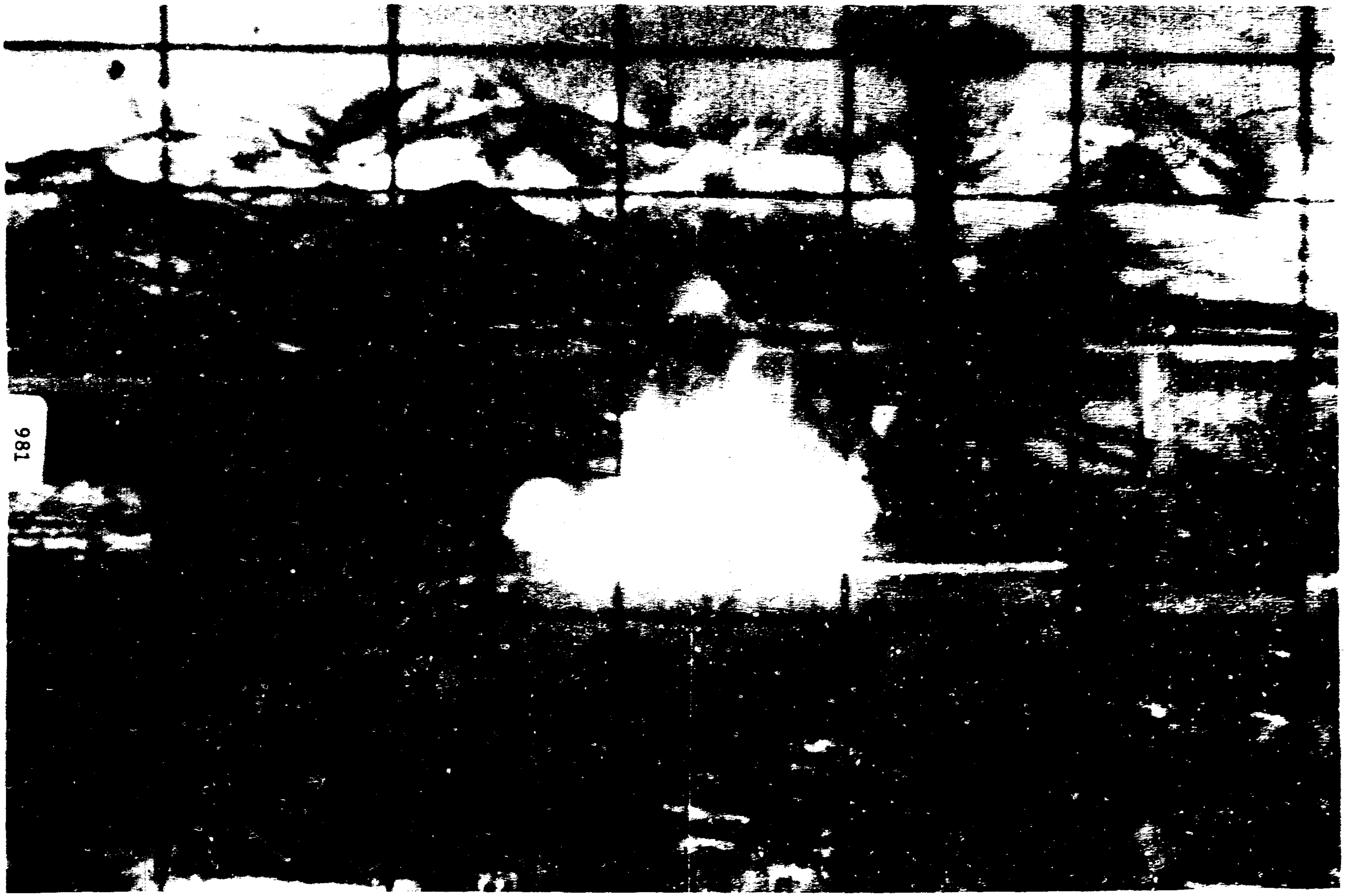
SLIDE 13


EXPLOSIVE WASTE INCINERATOR
BAGHOUSE
MOLTEN METAL RECOVERY CONVEYOR (OPTIONAL)
FURNACE ENCLOSURE
DISCHARGE CONVEYOR
SCRAP RECOVERY SYSTEM (OPTIONAL)
EXHAUST STACK
FAN
CYCLONE
GAS COOLER
AIR COMPRESSOR
DEACTIVATION FURNACE
CONVEYOR RETRIEVAL SYSTEM
POSITIVE FEED SYSTEM
PURGE PANEL
CONTROL PANEL
FEED BUILDING
FEED CONVEYOR
LOADING DOCK

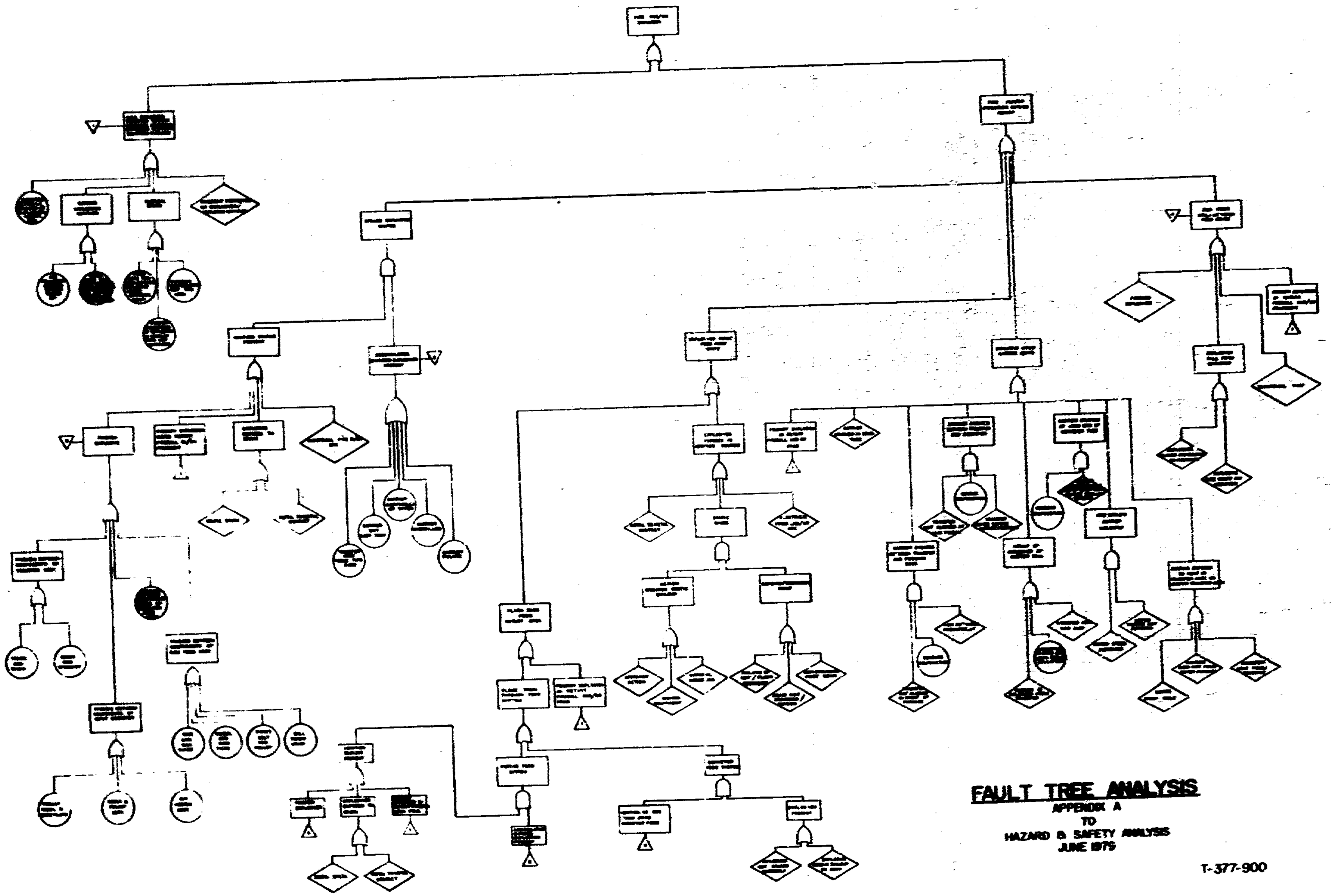
SLIDE 14



SLIDE 15



SLIDE 16


FAULT TREE ANALYSIS
APPENDIX A
TO
HAZARD & SAFETY ANALYSIS
JUNE 1975
T-377-900

SLIDE 17

CONTAMINATED WASTE PROCESSOR

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INTRODUCTION

The purpose of this paper is to describe the basic characteristics of the Contaminated Waste Processor that has recently been designed by the Army and will be installed at a number of facilities throughout the United States in the next two or three years.

During normal operations at Army ammunition plants and Army depots, large quantities of waste are generated that is known or suspected to be contaminated with explosives or propellents. During these same and other types of operations (i.e., washout plant operations), large quantities of metals are also generated that are potentially contaminated with explosives or propellents. Because of the hazardous nature of these explosive contaminated metals, they cannot be sold directly to the private sector. It is a requirement that the contaminated waste be destroyed by the Army and that the explosive contaminants in the metal be flashed away before the metal can be sold for recycling.

Historically, contaminated wastes and metals have been incinerated or flashed, respectively, on open burning grounds at the various facilities. In some cases, the contaminated wastes have also been land filled. With the implementation of the Clean Air Act and the Resource Conservation and Recovery Act, the Army has been prompted to develop alternative processes. The first system considered was the Air Curtain Destructor (ACD). The Air Curtain Destructor is a large concrete lined pit wherein the contaminated wastes and metals are placed for incineration and flashing. The Air Curtain Destructor operates by blowing large quantities of air over and

around the contaminated wastes to provide complete combustion. When the first facility was installed it was found that it exceeded the particulate standards of many states. In some cases, State Evironmental Enforcement Agencies considered the ACD the same as open burning. The ACD was evaluated to determine if the combustion process could be improved or if an Air Pollution Control System could be fitted to it. It was determined that the combustion process probably could not be changed greatly and that it was not feasible from an economic point of view to add an Air Pollution Control System because of the large quantities of air that would have to be processed. Another problem with the ACD is that there is no method of assuring that the metals have been decontaminated due to lack of temperature and time history.

It was proposed by Tooele Army Depot's Ammunition Equipment Office (AEO) that a modification of the Army's Standard APE 2048 Flashing Furnace would provide a Contaminated Waste Processor (CWP) that would meet future air pollution requirements. The APE 2048 is a car bottom furnace designed and tested for decontaminating metal parts at a rate of 8000 lb/hr. The furnace is 13 1/2' long, 4 1/2' high and 6 1/2 wide.

The furnace is a refractory lined, oil fired, batch type process furnace to burn off residual explosives from bomb and projectile casings after the casings have been processed in an explosive removal facility. A picture of the furnace is shown in Figure 1. The furnace chamber is lined with a lightweight ceramic fiber backed with mineral wool block. The furnace car bottom has a top surface of abrasion resistant castable refractory, whereon trays holding the parts to be decontaminated are placed. The doors, which are closed during normal furnace operation, are lined with a ceramic fiber blanket. Two burners are located at the front of the furnace chamber on each side and slightly above the exhaust duct. When used as a flashing furnace, all the air is brought into the system through the burners. For ammunition decontamination, the furnace is first preheated to approximately 1000°F then the car bottom loaded with trays of items to be decontaminated are placed into the oven. The furnace/contaminated materials are heated up

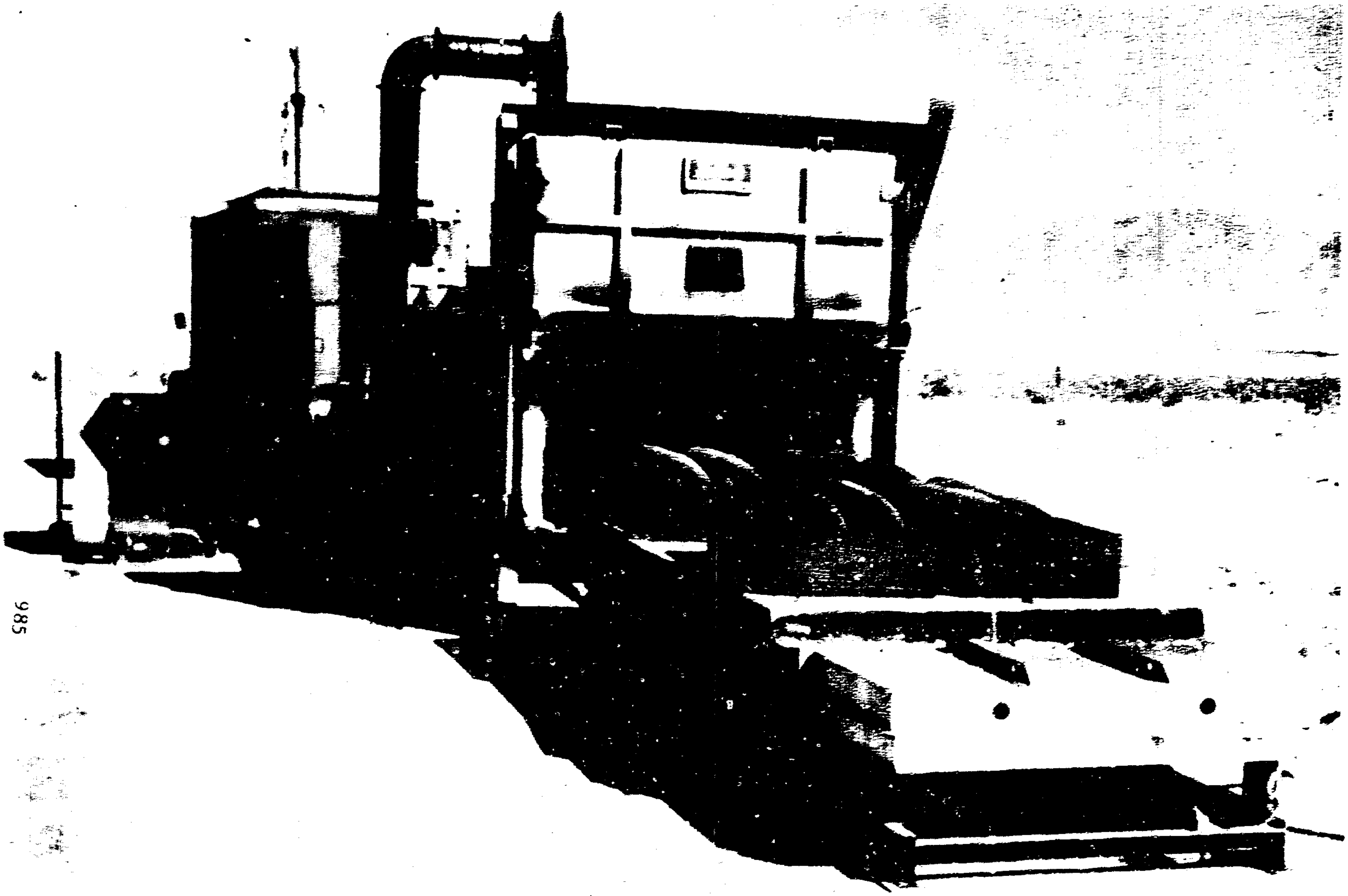


FIGURE 1: APE 1236 DEACTIVATION

to the flashing temperature (between 500°F and 1000°F) required for decontamination and maintained there for the required time. The burner settings are automatically controlled such that they are at low setting whenever the furnace door is open and at high fire setting or setting required to maintain the process temperature when the door is closed.

The AEO proposal for using the APE 2048 was based on four suppositions:

1. The modified 2048 as a Contaminated Waste Processor would result in more thorough combustion than the air curtain destructor.

2. The 2048 CWP would insure the decontamination of metals by providing a means of documentation that the materials ascertained a known temperature exposure for a known period of time.

3. The exhausts of the modified 2048 would exit through an exhaust stack entirely compatible with an air pollution control system (APCS).

4. The modified APE 2048 furnace would be economical to build and operate.

AEO was tasked by DARCOM to evaluate the feasibility of using the APE 2048 in a Contaminated Waste Processor System. The types and amounts of contaminated wastes generated at the Army's ammunition load lines were surveyed and tests conducted to demonstrate the capabilities of the modified 2048 for handling the wastes.

CONTAMINATED WASTE SURVEYS

Two contaminated waste surveys were made for the CWP: 1) a preliminary survey by the Ammunition Equipment Office prior to the demonstration tests and a later in-depth survey at seventeen facilities by a private contractor-Roy F. Weston Environmental Consultants. In both cases it was found that large quantities of combustible wastes and metals are generated. A summary

of the typical types of wastes and metals are shown below:

CONTAMINATED WASTE	CONTAMINATED METAL
Fiber Tubes	Munitions
Liners	Bombs
Ammo Boxes	Pipe
Oil Soaked Rags	Tanks
Coveralls, Gloves, etc.	Equipment
Tires	Metal Parts
Conveyor Belts	
Sawdust	
Pallets	
Railroad Ties	

The survey indicated that contaminated wastes were generated at rates up to 6,000 lbs/day (1.5 million lbs/yr) with contaminated metal generated at rates up to 14,000 lb/day (3.5 million lbs/yr) depending on the facility. A summary showing the average generation rates over a three year period at the facilities surveyed is shown below:

INSTALLATION	CONTAMINATED WASTE (lb/yr)	CONTAMINATED METALS (lb/yr)
Anniston AD	1,320,000	631,000
Badger AAP	131,000	230,000
Holston AAP		652,000
Iowa AAP	526,000	602,000
Kansas AAP	648,000	223,000
Letterkenny AD	1,025,000	776,000
McAlester AD	836,000	3,575,000
Milan AAP	817,000	638,000
Pueblo DA	8,800	679,000
Savanna DA	4,300	73,000

INSTALLATION	CONTAMINATED WASTE (lb/yr)	CONTAMINATED METALS (lb/yr)
Seneca AD	6,000	367,000
Sierra AD		32,000
Sunflower AAP	217,000	54,000
Tooele AD	259,000	1,799,000
Volunteer AAP	159,000	316,000
Lex-Blu AD	1,397,000	412,000

Demonstration/Development Tests

Demonstration tests and later development tests were made using the wastes types listed above. Prior to making the tests, minor modifications were made to the furnace which involved installing duct work to the top of the exhaust stack through a 20 hp fan to provide a forced draft.

The objectives of the demonstration tests were to:

1. Determine if the APE 2048 Flashing Furnace could be used as a contaminated waste processor.
2. Determine what modifications would be required to convert the 2048 to a CWP without loosing its capability to decontaminate metal parts.
3. Gather emission data and define air pollution control system requirements.
4. Define optimum parameters for operating the furnace.

Each burn was accomplished by preheating the furnace to a minimum of 1000°F, with the furnace door closed. The car was then withdrawn, materials placed on the car, and the car returned to the furnace. During the demonstration tests, the door remained partially open throughout the burn to to facilitate observation of the waste combustion and to serve as an air intake port. During later development tests, one burner was turned off and air was injected into the furnace through the burner port. By controlling

the burner/air injection rates, the furnace incineration rate was nearly doubled over the early test results.

Test Results

The test results have indicated that the modified furnace has excellent combustion characteristics. Stack sampling was performed during the demonstration tests under the direction of the Army Environmental Hygiene Agency. The emissions sampling consisted of:

1. Particulate sampling using a particulate sampling train.

2. No_x measurements using a Beckman Model 951 chemiluminescent Instrument.

3. CO, O_2, and CO_2 measurements using a Hamilton Fisher Gas Partitioner or Orsat.

4. Exhaust temperatures at the furnace stack and fan exhausts were continuously recorded. The temperatures at the sampling location was monitored with a fast acting hand held thermocouple and meter.

During the tests, essentially no visible smoke was present. The measured particulate levels nearly met the incineration standards of many states without either an afterburner or an air pollution control system. The stack sampling data indicated an average particulate grain loading of 0.03 gr/SCF and essentially no NO_x (less than 30 ppm) was present. CO was below detectable levels.

It has also been found that the furnace exhibits excellent temperature control characteristics so that we can be assured of destroying any hazardous or toxic materials that may be placed in the furnace. The CWP furnace is being designed with longer residence times in the stack (0.5 seconds) than was attained in the modified APE 2048 to provide greater assurance of complete combustion.

Figure 2 shows a picture taken of a typical test burn. The exhaust at the top of the fan to the left of the furnace shows the low opacity of the exhaust gases (nearly invisible).

Furnace Characteristics

The furnace tests have demonstrated excellent operating/system characteristics. Because of the high incineration rates per pound of air flow, the furnace can be operated with an air pollution control system with minimum energy usage. The furnace is also very versatile in that it can be operated to burn contaminated wastes, flash metal or run mixed loads. Knowledge that the metal is decontaminated can be assured from the recorded time and temperature history in the furnace.

Based on the test data, the energy consumption is expected to be minimal. The fuel consumption for incinerating combustible waste continously is expected to be 2 gallons per hour.

Contaminated Waste Processor Design

The Corps of Engineers, Huntsville Division named the Ammunition Equipment Office "Center of Technology" for the Contaminated Waste Processor and the Norfolk Distric "Center of Competance" for Brick and Mortor directing that the Contaminated Waste Processor design be made.

The Contaminated Waste Processor consists of three main subsystems with their associated controls: 1) the carbottom furnace, 2) an air pollution control system, and 3) two feed systems.

The basic facility layout is shown in Figure 3. The waste will be brought into the facility and dumped into the loading area from either of the two doors shown. A barricade wall of 1/8 inch steel is provided between the loading end and the furnace end of the building. This wall is designed to provide secondary fragment protection for operators in

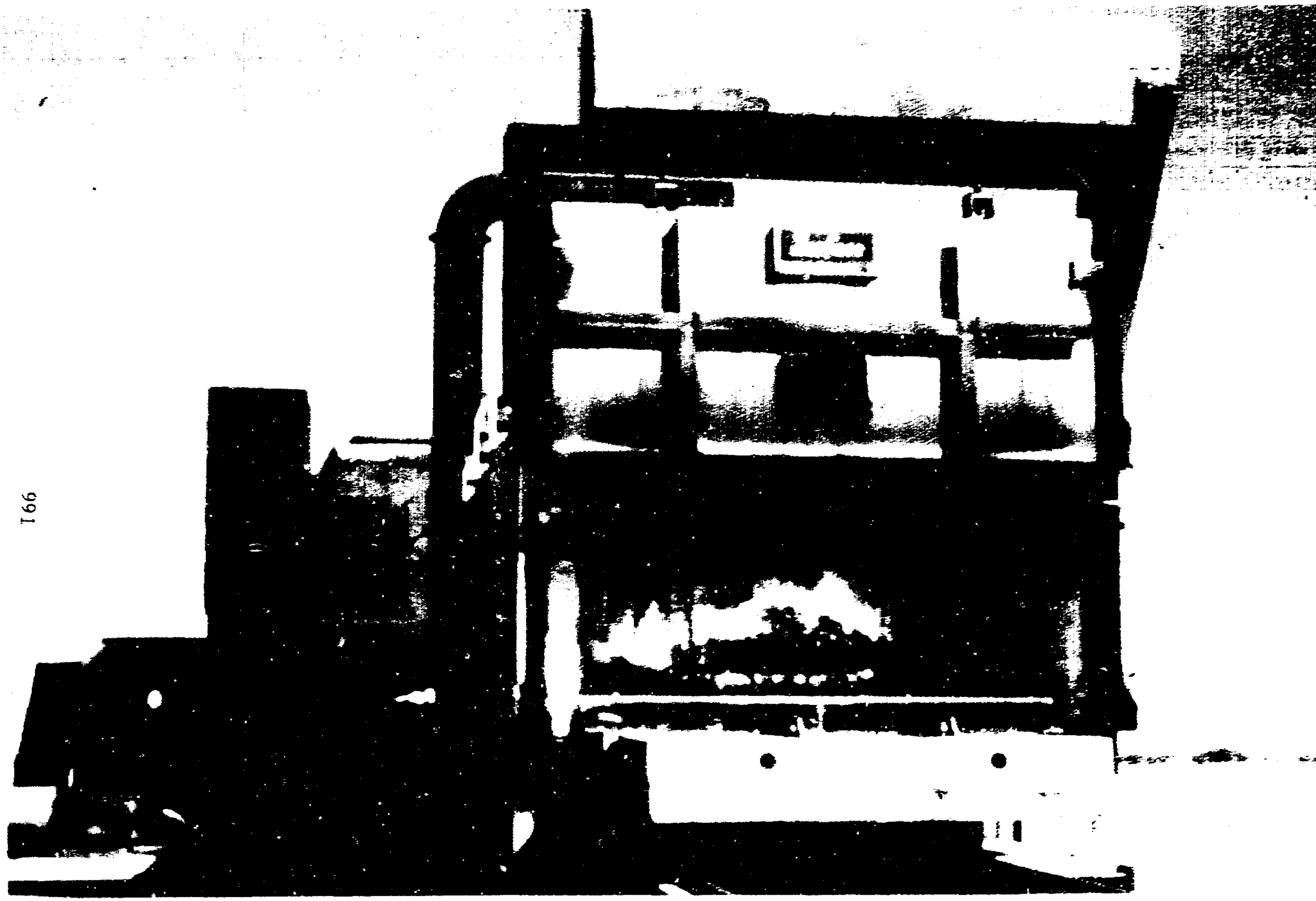


FIGURE 2: TYPICAL TEST BURN

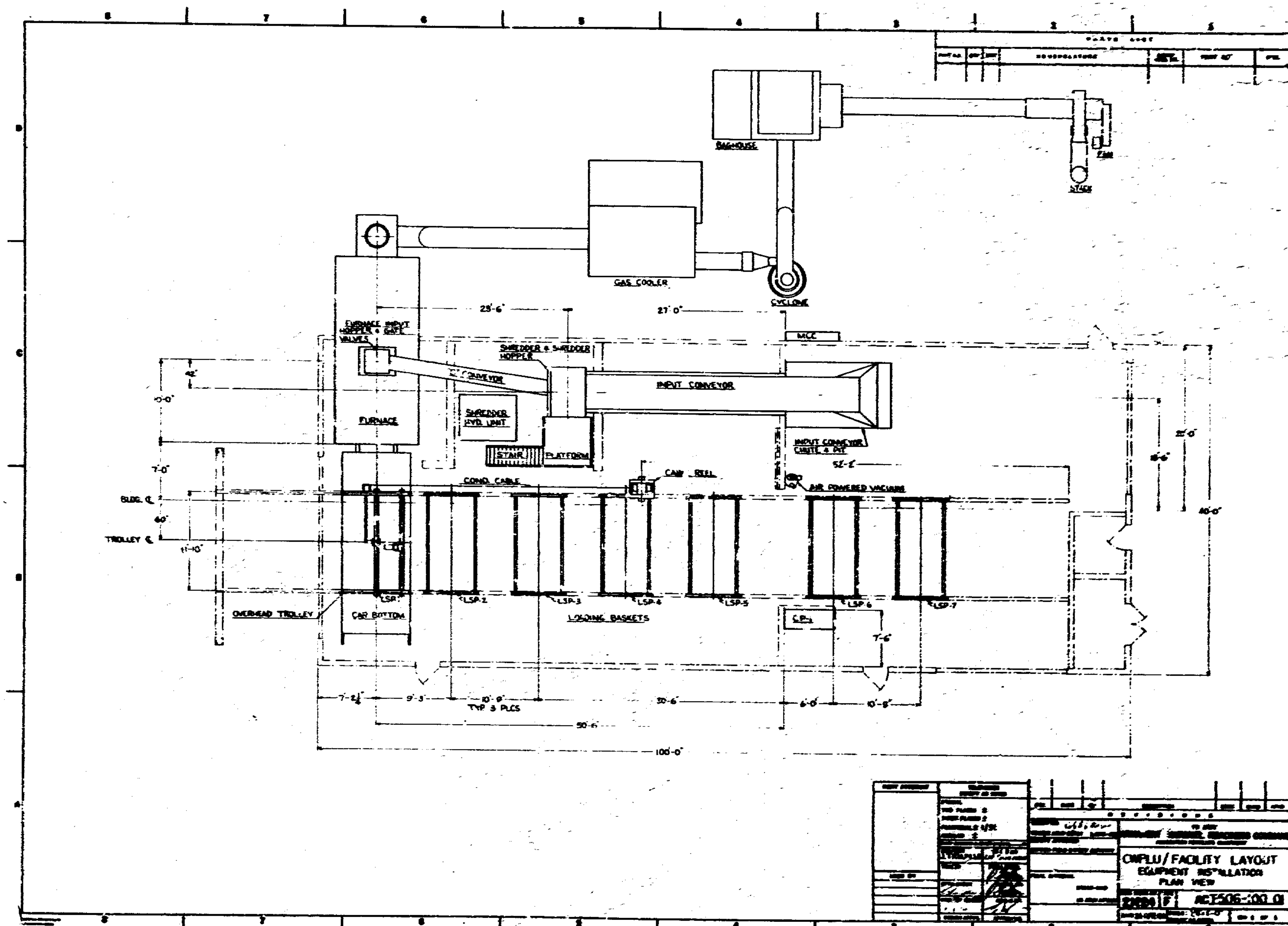


FIGURE 3: CWP FACILITY LAYOUT

the loading area. Reinforced concrete barricades are located around the shredder and furnace to provide for primary fragment protection. Although it is expected that up to 3 lb of explosive may be distributed in the furnace at one time, the maximum credible incidence is based on 1 lb of explosive. The barricades are sized for 1 lb of concentrated HE (pipe bomb or munition) resulting in a barricade thickness equivalent to 1 inch steel. The furnace is located with the front end inside of the building and the back end outside of the building as shown. The air for the furnace is taken from inside the furnace area and processed through the air pollution control system eliminating fugitive emissions.

Furnace Design

The furnace design is shown in Figure 4 and is basically the same as the 2048 demonstration furnace except that it is larger, (22' long x 8.5' wide x 6.5' high) modified for a conveyor top dump, has controlled air injection ports, and an automatic control system. The burner, exhaust duct, chamber configuration, refractories and ceramic fiber insulation material remain essentially the same. Automatically controlled air injection ports are implemented to maintain proper furnace draft, control exhaust temperature, and optimize waste combustion. A large and small burner is provided. The large burner will be off during most of the burn with the small burner modulated to provide temperature control.

It is anticipated that the furnace design will operate more efficiently than was demonstrated by the 2048 during feasibility and development tests. Although the furnace will be designed with a capacity and control system that will minimize load monitoring, the possibility of improper loading causing smoke release would always exist. Also it is recognized that the continuous feed system may stir up a certain amount of ash when in use that was not present in the feasibility tests. An air pollution control system will thus be used to assure compliance with emission standards under all operating conditions.

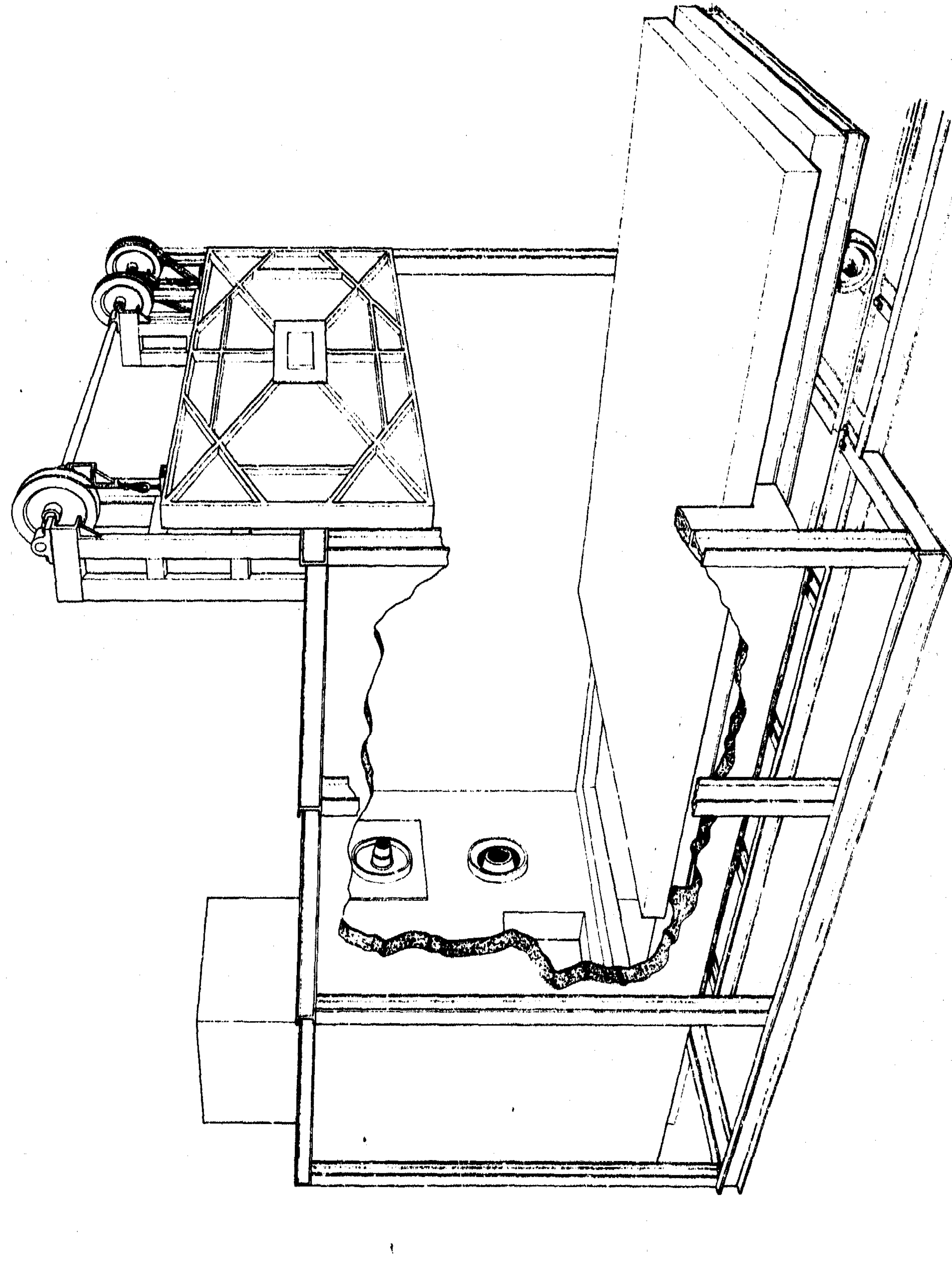


FIGURE 4: FURNACE LAYOUT

Based on the results of the preliminary contaminated waste survey made by the AEO and the workload expected by various Army organizations, the CWP was designed to incinerate 600 lb/hr of combustible waste when batch loaded. It is expected that the furnace will incinerate between 800-1000 lb/hr of waste when operated with continuous feed.

The furnace was also to be designed to be capable of flashing large quantities of contaminated metal- 10,000 lb/hr. The furnace carbottom and burners have been sized accordingly, although it is expected that the metals will generally be flashed when incinerating mixed waste-metal loads for minimum fuel usage.

Air Pollution Control System

The CWP air pollution control system is shown in Figure 5. The APCS consists of a gas cooler, cyclone, baghouse, exhaust fan, and exhaust stack. The furnace exhaust gases (1600°F, 4000 SCFM) will be cooled to 900°F with dilution air. The gas cooler will cool the exhaust gases to provide a gas temperature of 250°F which is within the operating limits of the baghouse. The gas cooler is used to minimize the exhaust fan power requirements as well as exhaust gas processing requirements. The exhaust gas will then pass through the cyclone to remove particulate down to approximately the 30 micron size followed by the baghouse for removal of particulate to 0.5 micron. It is expected that better than 99% of the emitted particulate will be removed by the cyclone/baghouse combination. The exhaust gases (250°F) will then pass through the fan, which provides a negative draft on the CWP system, and exits out the exhaust stack.

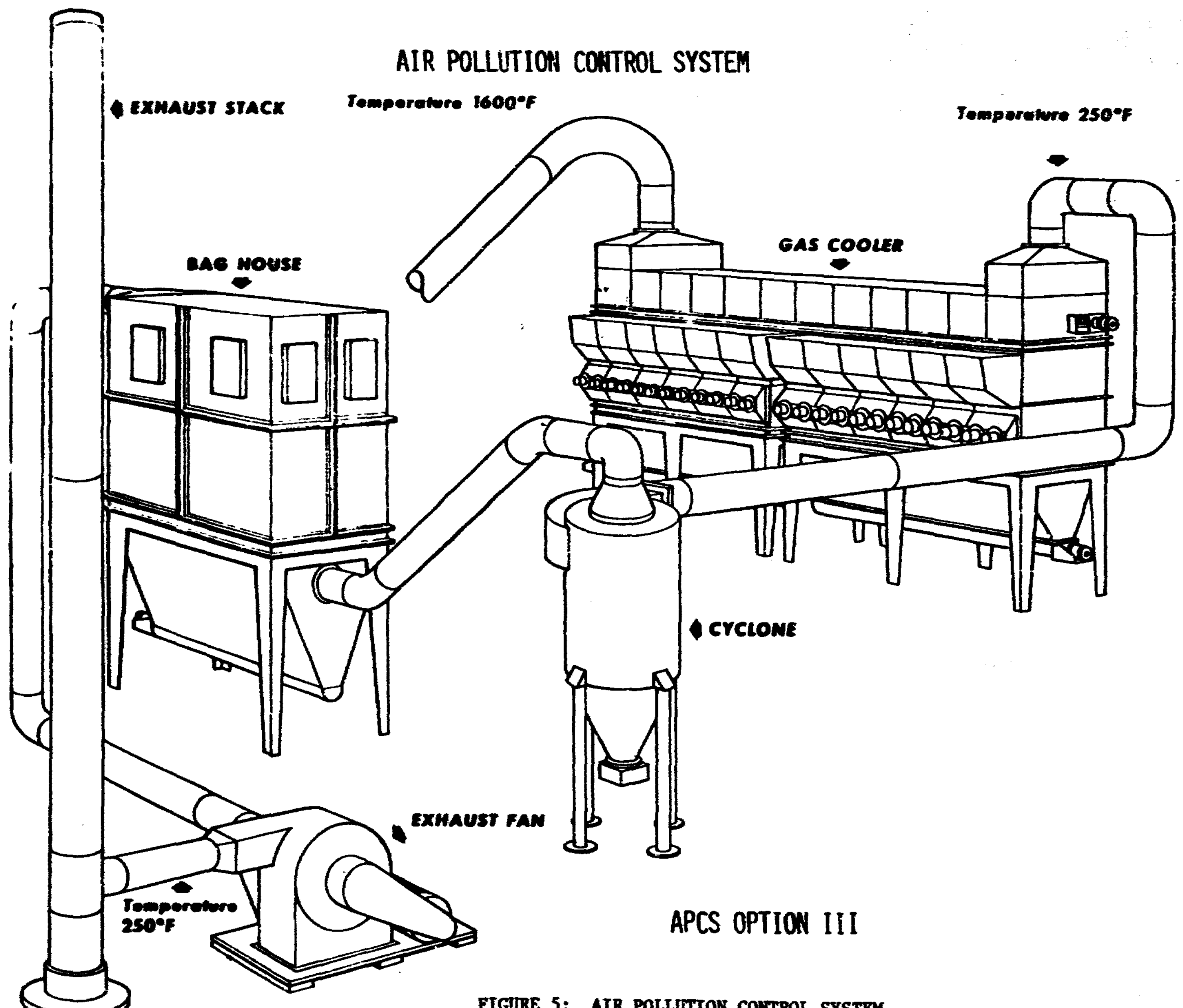


FIGURE 5: AIR POLLUTION CONTROL SYSTEM

Feed Systems

Two types of feed systems will be provided for the CWP: 1) A batch loading system; and 2) a continuous furnace top dump conveyor system with front end preparation. The overhead trolley batch loading system uses baskets as a means of collecting and holding the waste as it is destroyed in the furnace. The baskets are 6' wide x 12' long x 2' high and are fabricated of steel with wire braided sides and bottom tray to catch the ash and residue. The baskets are loaded in the loading area and are picked up and transferred to the furnace by the overhead trolley. Quick release hooks remotely controlled, load and unload the baskets to insure the safety of an operator. The system is controlled automatically by a microprocessor control system. The basket/trolley system can be seen in Figure 6.

The top dump continuous conveyor feed system will increase the processing capacity of the furnace as well as its flexibility. The waste will be loaded onto a continuous feed conveyor and carried to the shredder. The industrial waste shredder is driven by a hydraulic motor with automatic hydraulic anti-jamming reversing capabilities. It is capable of shredding pallets, 55 gallon drums, railroad ties, wire, cable, light gauge scrap metal, cloth, paper and cardboard. It has shredding rates to 120 pallets per hour and can process approximately 40-55 gallon drums per hour. The shredded waste will be carried from the shredder via a cleated conveyor and dumped into the furnace through a double sliding valve/air lock system. The continous feed system is also shown in Figure 6.

Figure 7 shows a general vew of the external part of the building, the access areas, and the general APCS layout.

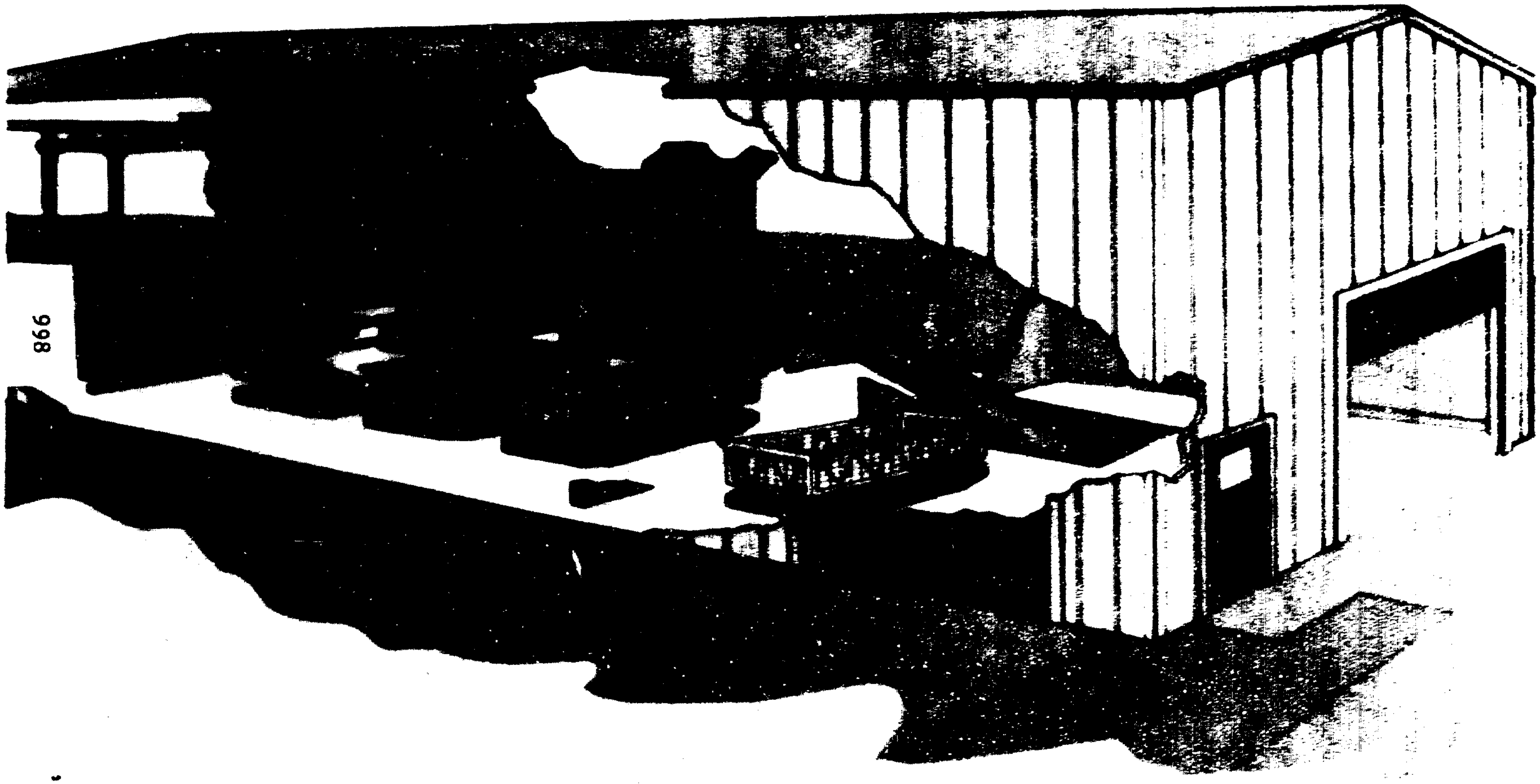


FIGURE 6: CWP FACILITY

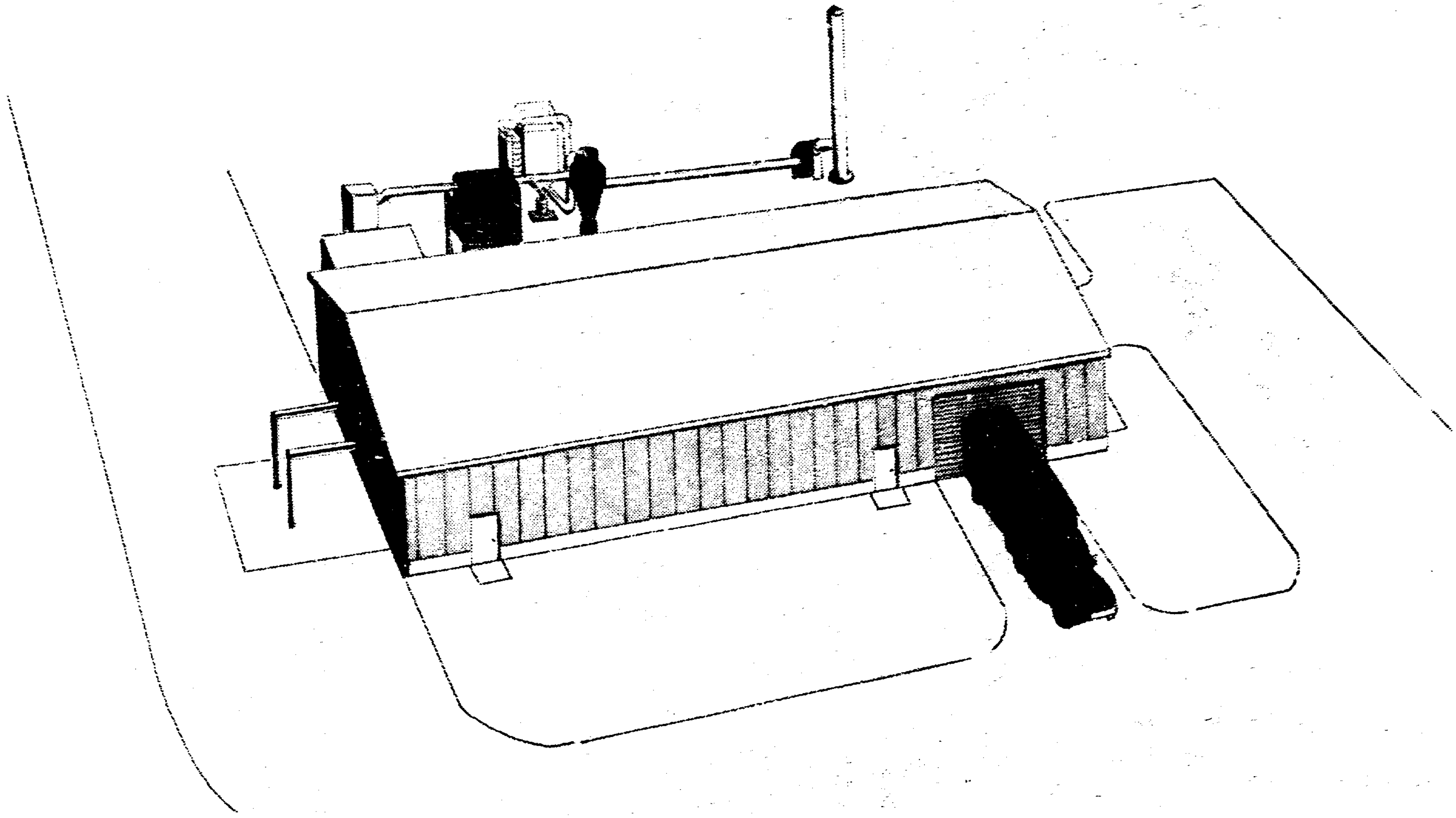


FIGURE 7: CWP FACILITY LAYOUT

CONCLUSIONS

The demonstration/development tests of the modified APE 2048 furnace have indicated that contaminated wastes generated at Army ammunition plants and depots can be effectively incinerated.

It is expected that the CWP system with a complete air pollution control system will meet all current and future emission standards of State and Federal EPAs.

The CWP will effectively flash metals and provide a record of the temperature-time history as a means of assuring decontamination.

The system is designed for minimum energy consumption through burner/air injection control and by the use of contaminated waste to flash contaminated metal.

RECYCLING EXPLOSIVES

By
Ralph W. Hayes
Ammunition Equipment Office

1. The current method for recovering explosive assets from unserviceable munitions is accomplished in a washout plant (Fig 1). This was one of the earliest technological developments for disposing of obsolete munitions by means other than open air detonation, and it recovered some of the assets from obsolete bombs and projectiles. The explosive was washed from the bombs with very hot, high pressure water by both melting and hydraulic mining of the explosive. The explosive was then dried, pelletized, and sold to the mining industry (Fig 2). Years ago this was considered a very efficient operation. Recently, with new emphasis on energy and the environment, the washout plant is becoming obsolete. A great deal of energy is required to wash the explosive and then dry it, and a considerable effort must now be undertaken to clean the water to current standards before discharging it. The explosive, because of the introduction of water into the system, does not meet military specifications as the waxes and other additives are changed in the process.

2. The Ammuntion Equipment Office (AEO) is investigating two procedures whereby this explosive can be recovered without the introduction of water and associated problems. It is anticipated that these recovered explosives could perhaps be recycled directly back into the loadlines (Fig 3). This would not only eliminate the pollution and costs associated with the disposal of the munitions, but also the manufacture of the explosive as well.

3. The first method takes advantage of previously developed technology. The Ammunition Equipment Office has developed a high production saw capable of remotely sawing projectiles in two (Fig 4). The saw is used to cut the projectile in the major internal diameter. It has been found that while loading projectiles when Comp B and TNT are poured into the projectile, the wax additives freeze on the explosive/shell interface. With only a slight addition of heat to the outside of the shell, the wax and explosive at the interface melt allowing the explosive slug to drop free. Figure 5 depicts a small prototype machine capable of melting out projectiles using low pressure steam applied externally to the shell. It has been found that the explosive slug can be recovered in about one half minute of melt time.

4. Figure 6 depicts explosive slugs from a recent melt test. Samples of this explosive have been sent to the Feltman Laboratory at Picatinny for analysis and it was determined that the explosive still meets military specification. Feltman Laboratory has been funded to determine methodology for reintroducing this explosive into the loadlines. This recovery method has tremendous advantage over the washout plant. The explosive, meeting military specifications, can be much more valuable if the technology for

recycling is developed. The operation is pollution free and the large energy expenditure is unnecessary since the heat is only used to melt a thin layer of wax and explosive.

5. Melt out procedures have also been investigated on bombs. As this figure shows a 750 pound bomb contains internal wiring conduit which prevents the explosive from dropping out in a single slug necessitating developing a different method of explosive recovery. Since it is necessary to melt all of the explosive in the bomb and pour it out, the melting process is extremely slow. For safety reasons, the amount of heat that can be applied externally to the bomb shell is very limited (225°F). If the bomb is placed with the exposed end downward, the explosive cannot be melted completely because as the explosive melts and falls away on the outside diameter, an air gap is formed which impedes the flow of heat to the center of the bomb. Therefore, it is necessary to heat the bomb with the exposed end upward and entirely melt the contents before pouring the explosive from the bomb. Experiments conducted by the Ammunition Equipment Office have shown that this operation takes 24 hours.

6. It was hypothesized that perhaps microwave energy could accomplish this melt out at a faster rate. Microwave heating is extremely unique in that the properties of the material being heated is the determining factor in the amount of energy absorbed in the operation. Tests were conducted for AEO by the Massachusetts Institute of Technology (MIT) to determine the loss factor and half power depth for various explosives. The loss factor is proportional to the ability of the material to convert the microwave energy into heat. From the data obtained from MIT, it was determined that Tritonal and Minol II were the best candidates for melting with microwave energy. The loss factor versus temperature for Minol II is shown in Figure 8. As can be seen, the loss factor for Minol II increases gradually with temperature until it approaches the melting point where it increases rapidly. These properties of Minol II and Tritonal are very significant because warm spots begin absorbing the energy much more rapidly than the cool surroundings, and a hot spot may be formed. The hot spots then begin absorbing all of the energy and a thermal runaway condition can result. This is very significant when the material being heated is explosives. Figure 9 shows our first impression of a thermal runaway condition of this material.

7. The half power depth (Fig 10) is the depth in the material at which the power is half of that at the surface. This number indicates the ease in which energy penetrates the material. For example a short half power depth means the material will be heating on the surface. A very large half power depth means the material is almost transparent to the microwave energy. Using this information it was postulated that bombs with the base plate removed could be placed with the open end downward and microwave energy beamed into this opening. The bomb shell would serve as the cavity or oven. It was also postulated that the energy could be introduced at such a rate that the explosive, melting at the surface, could fall free of the microwave field before becoming overheated. A small 2 1/2 KW, 2450 MHz microwave system was rented to conduct the initial test work (Fig 11). A bomb was placed in a bomb stand capable of rotation to provide more uniformity in heating. The

explosive surface was preheated to insure that hot spots would not be formed internally and then microwave energy was applied to the explosive surface. Using very sophisticated infrared camera techniques, the temperature of the explosive surface was measured throughout the melting operation. It was demonstrated that the explosive could be melted from the bombs.

8. Figure 12 depicts a 750 pound bomb that has been melted out using microwave energy. Fortunately the metal shell of the bomb interfers with the heating process at the explosive interface and the asphaltic liners are not melted. This leaves a product which is presumed to be uncontaminated and a candidate for recycling. It was determined that this melting procedure required less than 20KW hours of energy compared to 915KW hours in the washout plant. The next test was undertaken to determine the maximum melting rate using microwave energy. Since the Army already owned a large 25KW 915 MHz unit it was decided to use that unit rather than buy a new one, even though it was a different frequency (there are two frequencies available to industry).

9. The loss factor and half power depth of the explosives were again measured by MIT, at 915 MHz. It was observed that the half power depth greatly increased at this low frequency. This had two effects. A positive effect was that the maximum melting rate of the explosive would perhaps be greater than that at 2450 MHz. With the energy penetrating deeper in the explosive, the surface would not overheat as quickly as with all of the energy being absorbed right at the surface, and theoretically more power could be applied. However, the potential for danger increased with subsurface heating. Operating this unit at a power level of about 12KW, AEO successfully melted both Tritonal and Minol II bombs in approximately one hour melt time. A fire resulted in one of the tests. It was presumed that this was caused by the nonuniform mixture of explosive. A pocket of material more "lossy" than the material on the surface evidently existed. With increased energy penetration below the surface at this frequency, this material began to heat quicker than the material at the surface. This resulted in super heating the explosive trapped behind the surface, and the outbreak of a fire.

10. AEO is currently in the process of additional testing with microwave energy. We have purchased equipment at 2450 MHz, which was the original frequency, and the one which we believe has the biggest safety factor. These current tests are aimed at maximizing the safety of the operation and developing controls to enable us to field what has initially been a research and development effort, into a production unit. Figure 15 depicts our current test equipment. In summary, the technology for microwave melting has been fully demonstrated. The big challenge lies in providing depot organizations with sophisticated technology packaged in such a way that the safety of the operation is guaranteed without requiring specially hired operators with special technical knowledge.

11. In analyzing these two melt out techniques for recovering explosive, they both have tremendous potential for saving the government money, energy, and eliminating environmental insult. The steam out process can safely be assumed to have a very high confidence level for successful application to demil operations in the near future. Although the microwave melt out

offers tremendous advantages, the confidence level that this technology will be fielded soon, is not as high as with steam out because of the sophistication of the operation. We do feel confident, however, that there is a good chance that these obstacles will be overcome in the future test that we are now undertaking. Much of the success of both processes relies upon the ability of Feltman Laboratories developing the methodology for recycling this explosive back into the loading operations. With this technology firmly in hand, the Army could clearly demonstrate excellent examples of complying with the Resource Recovery Act and the many benefits resulting from recycling resources.

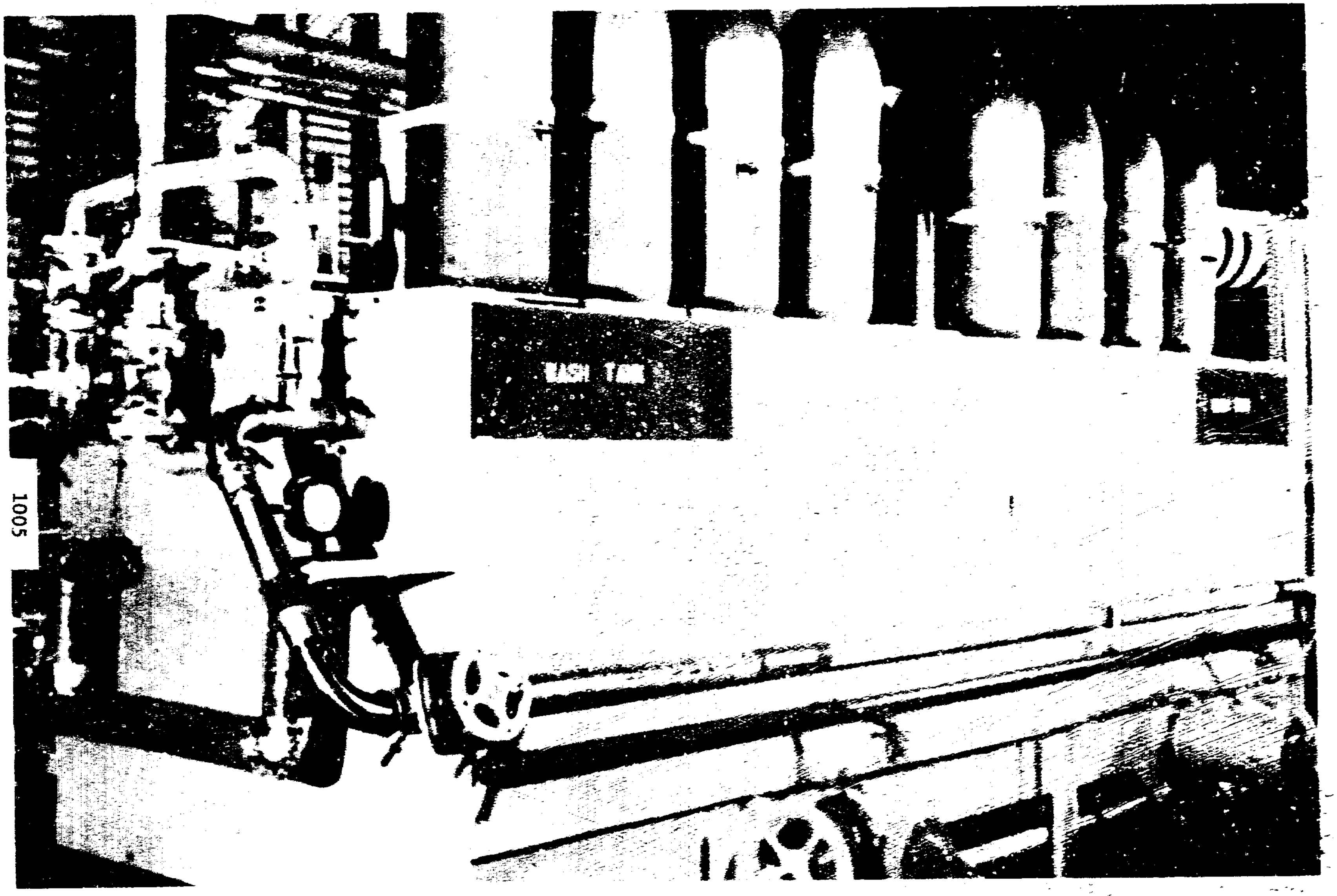


FIGURE 1

FIGURE 2

Recycling Explosive

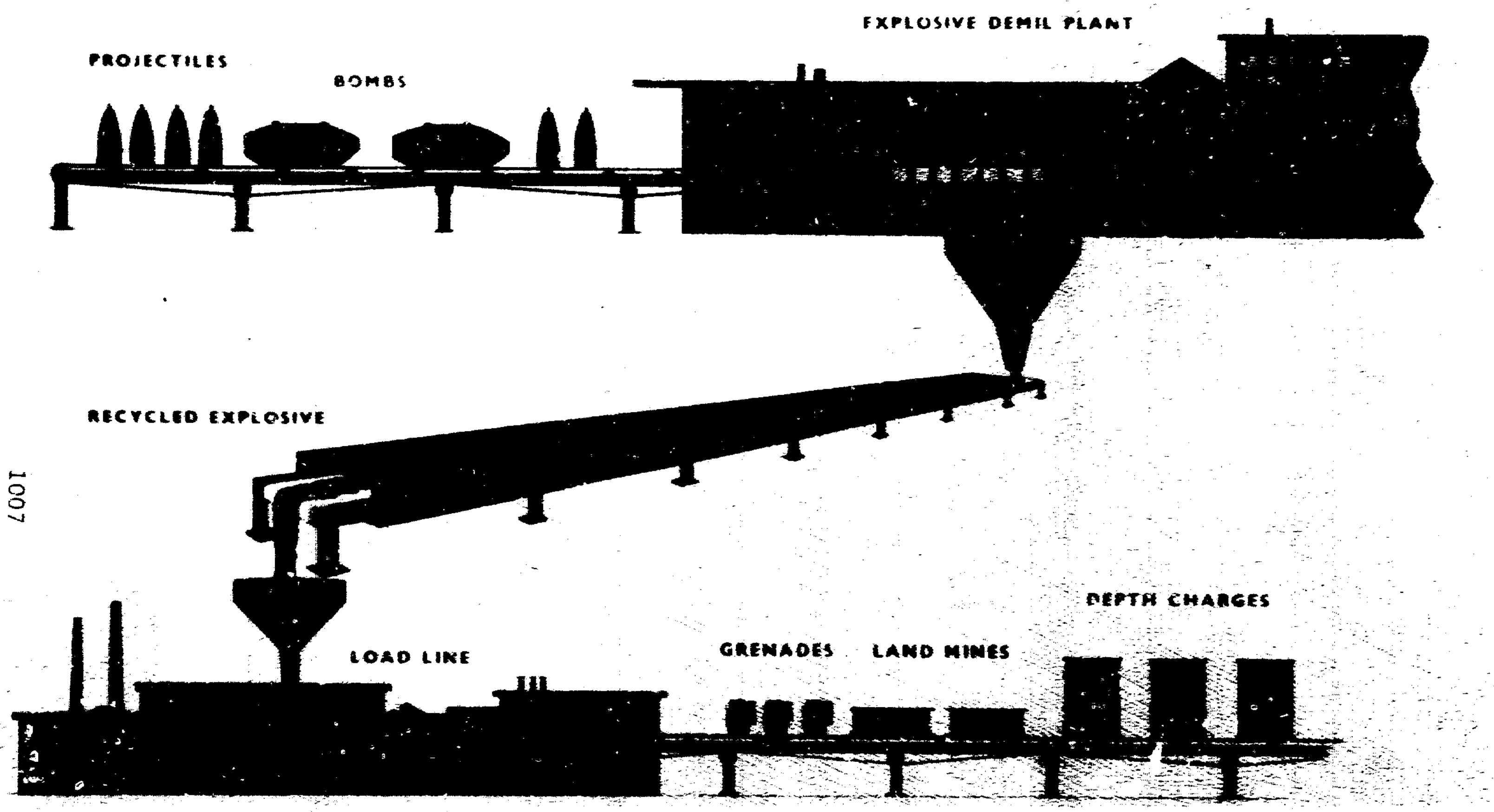
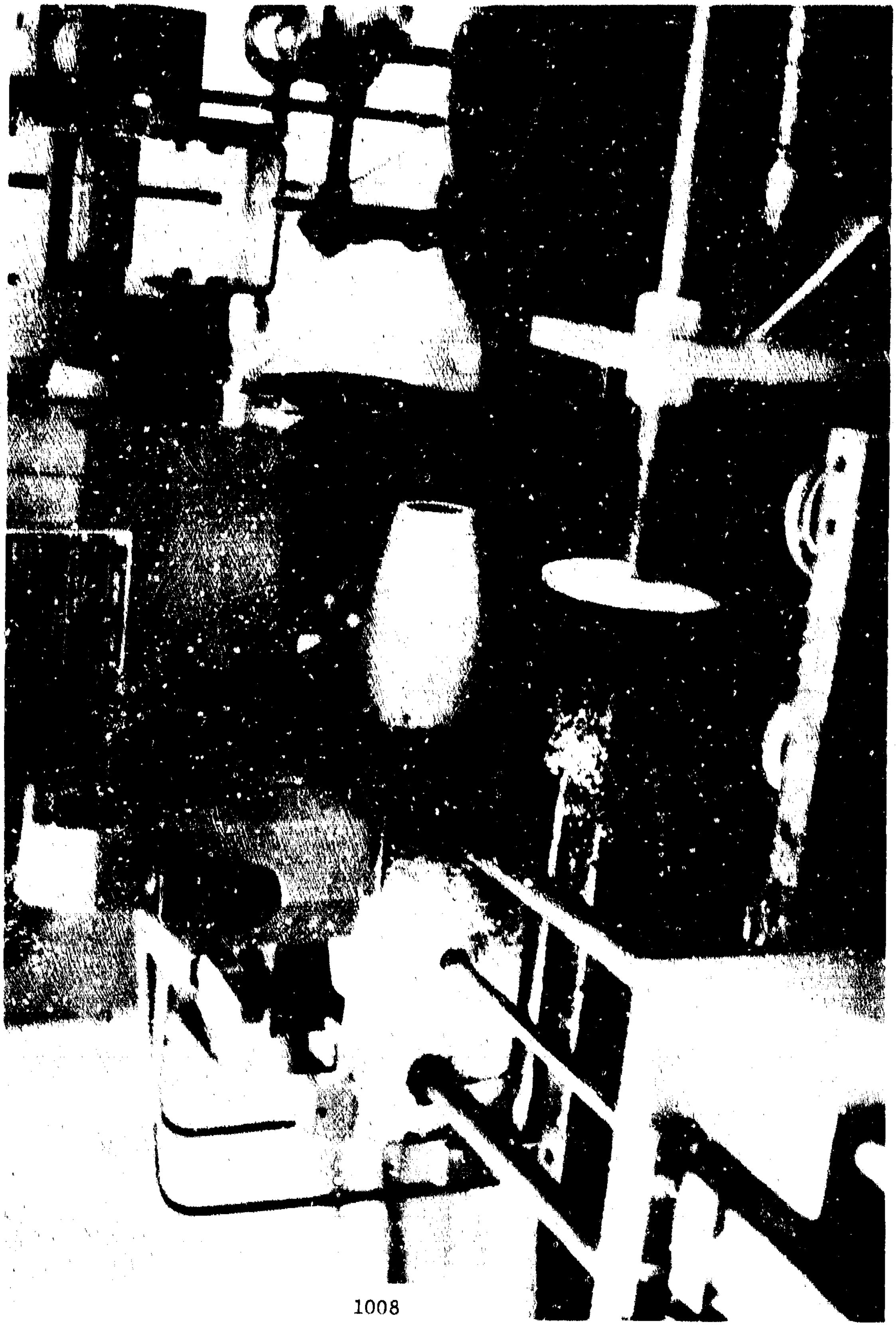


FIGURE 3

FIGURE 4



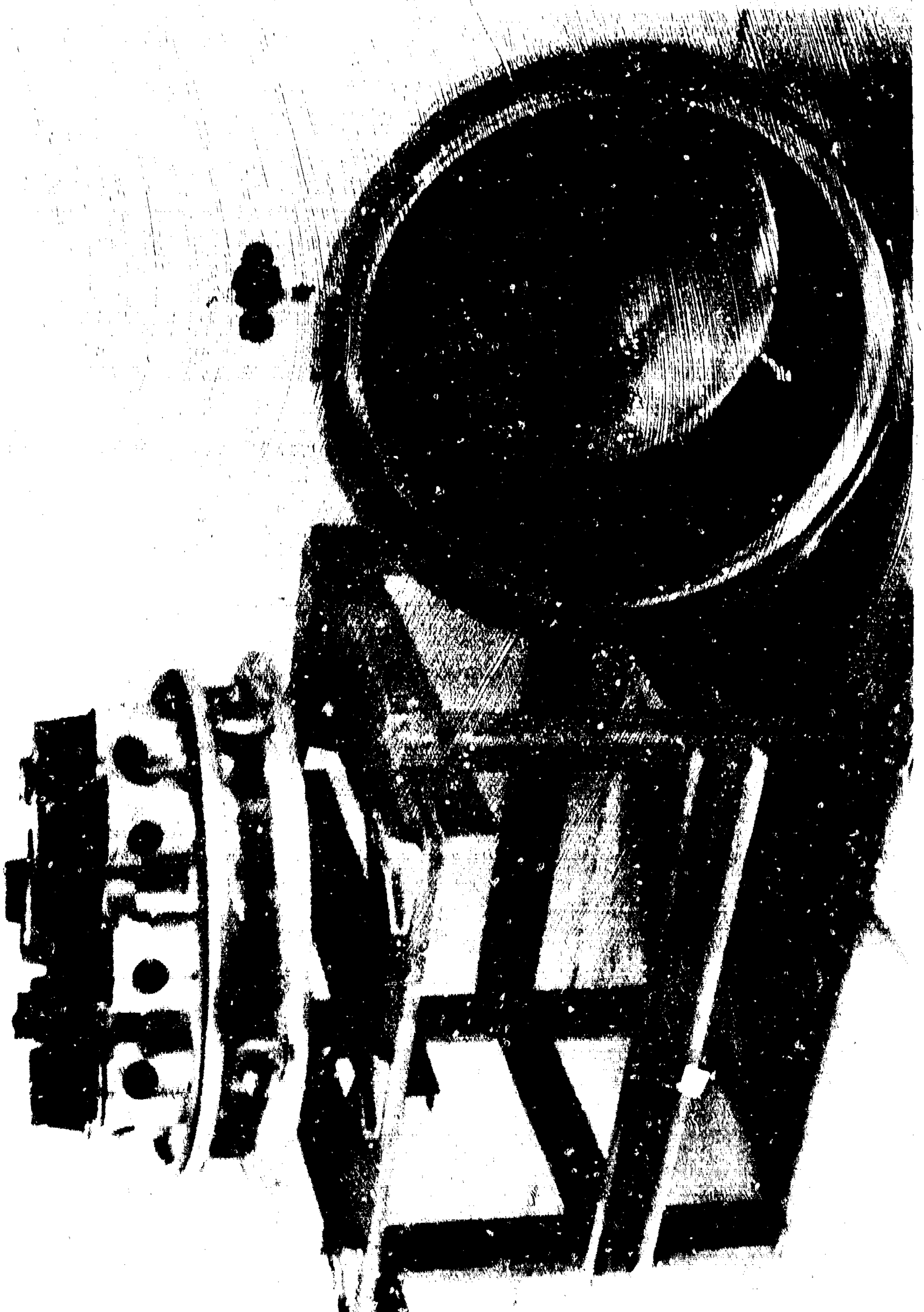


FIGURE 5

FIGURE 6

750 lb Minol II Bomb

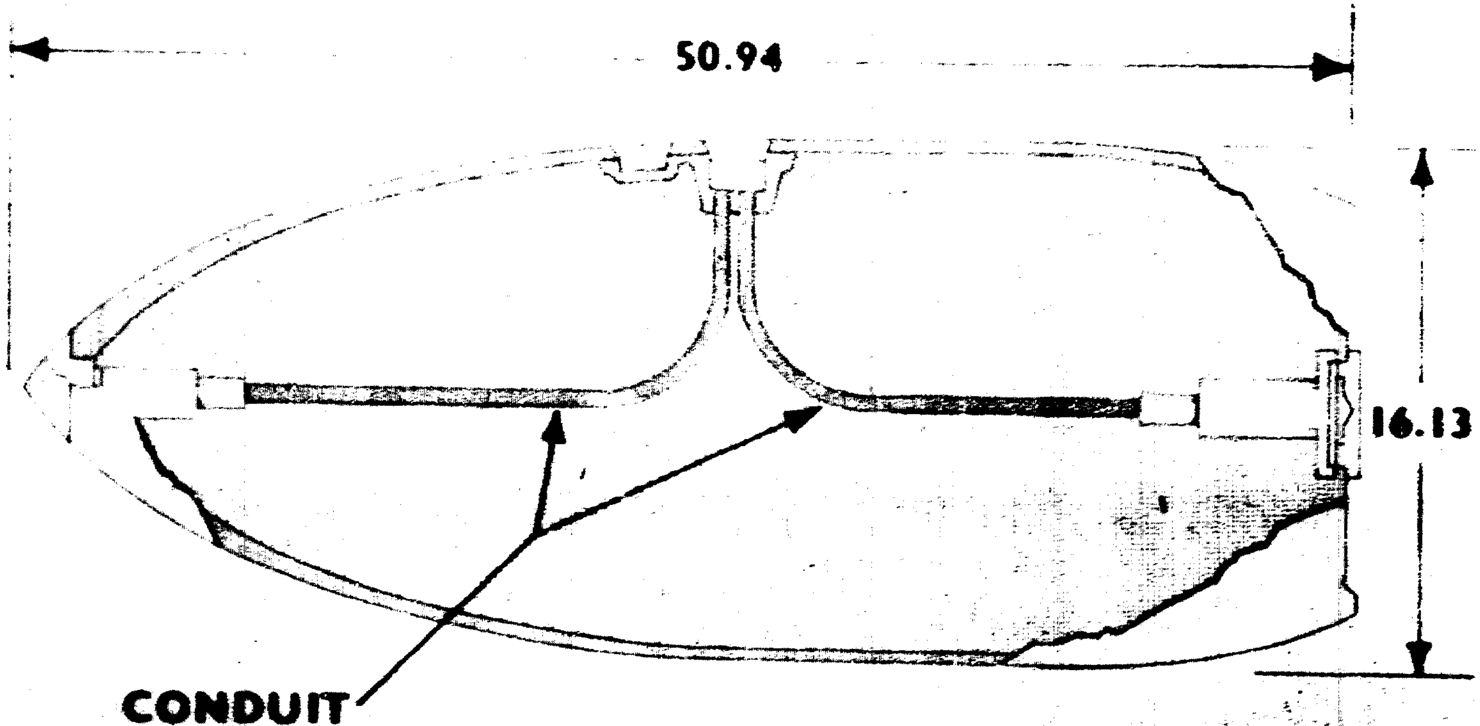


FIGURE 7

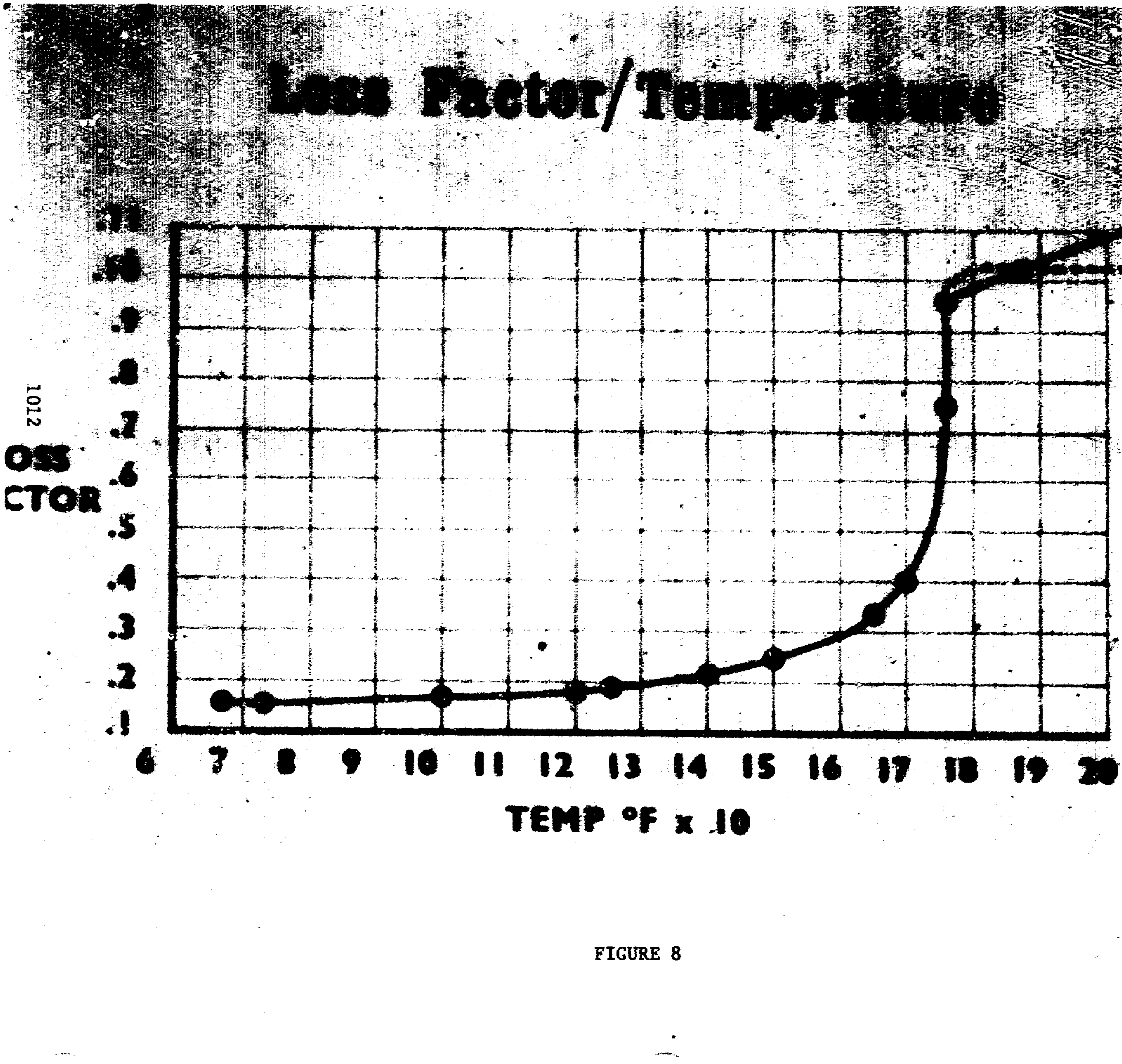


Fig 2

FIGURE 8

THERMAL RUNAWAY CONDITION

FIGURE 9

Half Power Depth Factor/Temperature

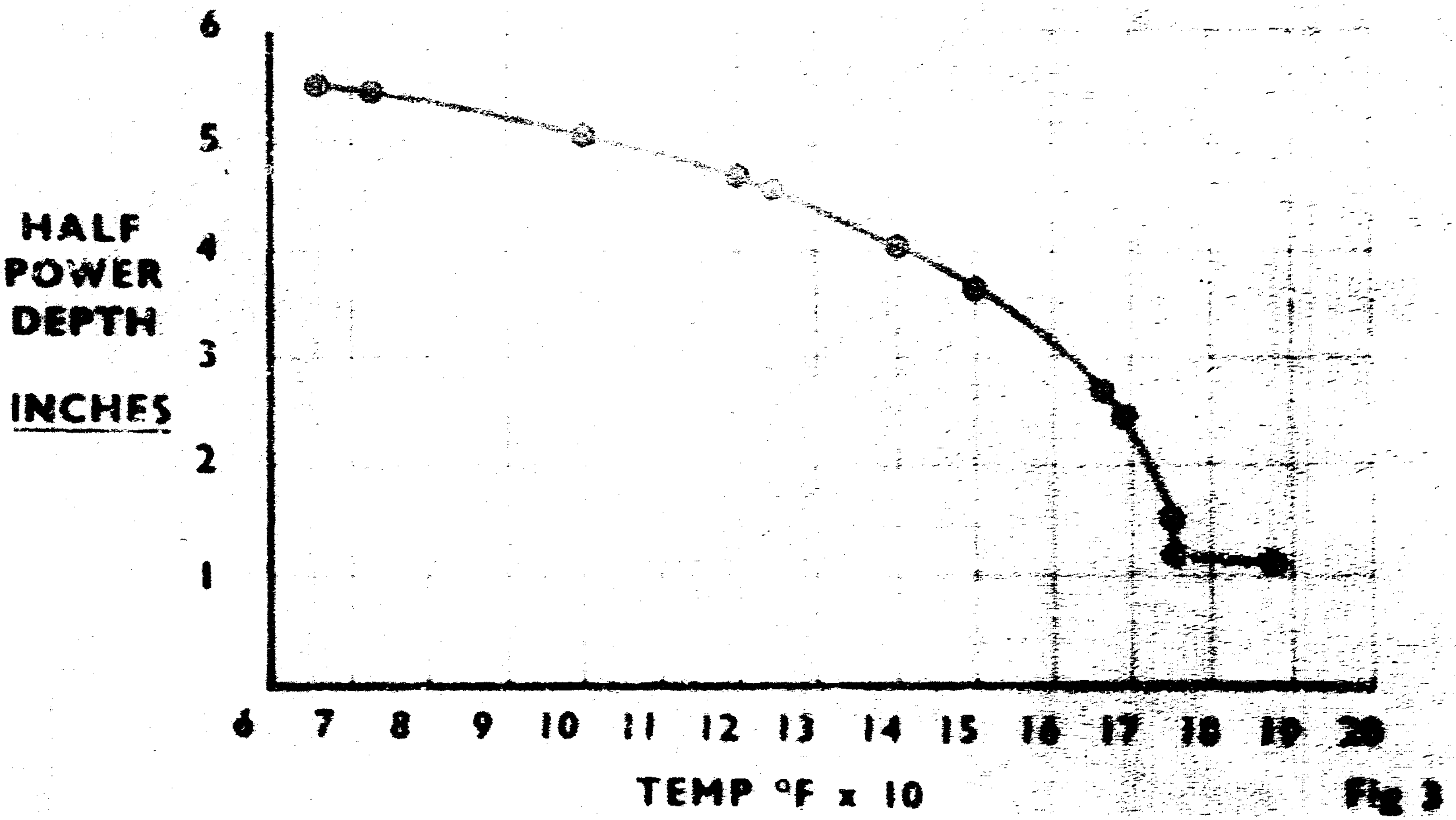


FIGURE 10

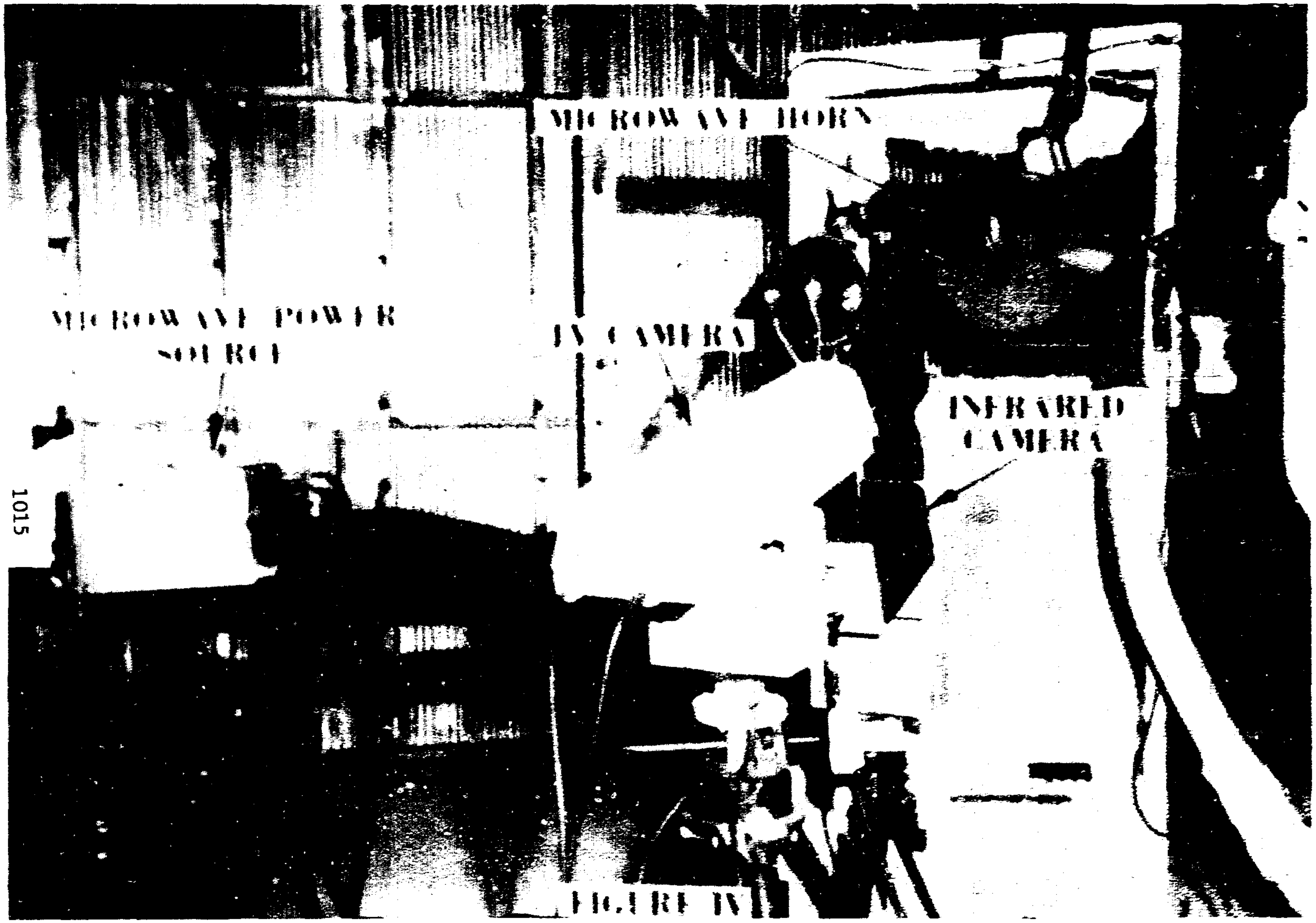

MICROWAVE HORN
MICROWAVE POWER SOURCE
TV CAMERA
INFRARED CAMERA

FIGURE 11

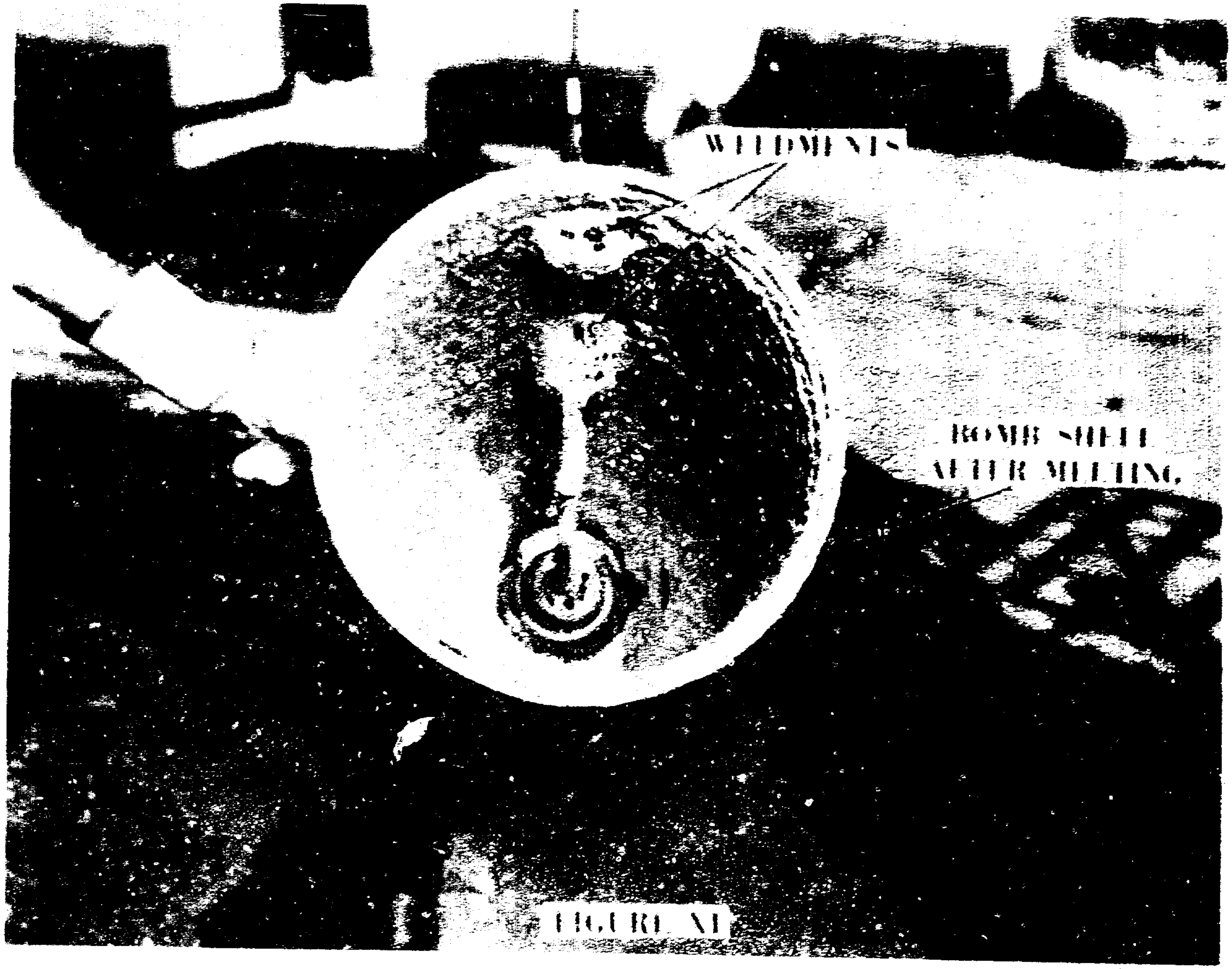


FIGURE 12

Loss Factor/Temperature

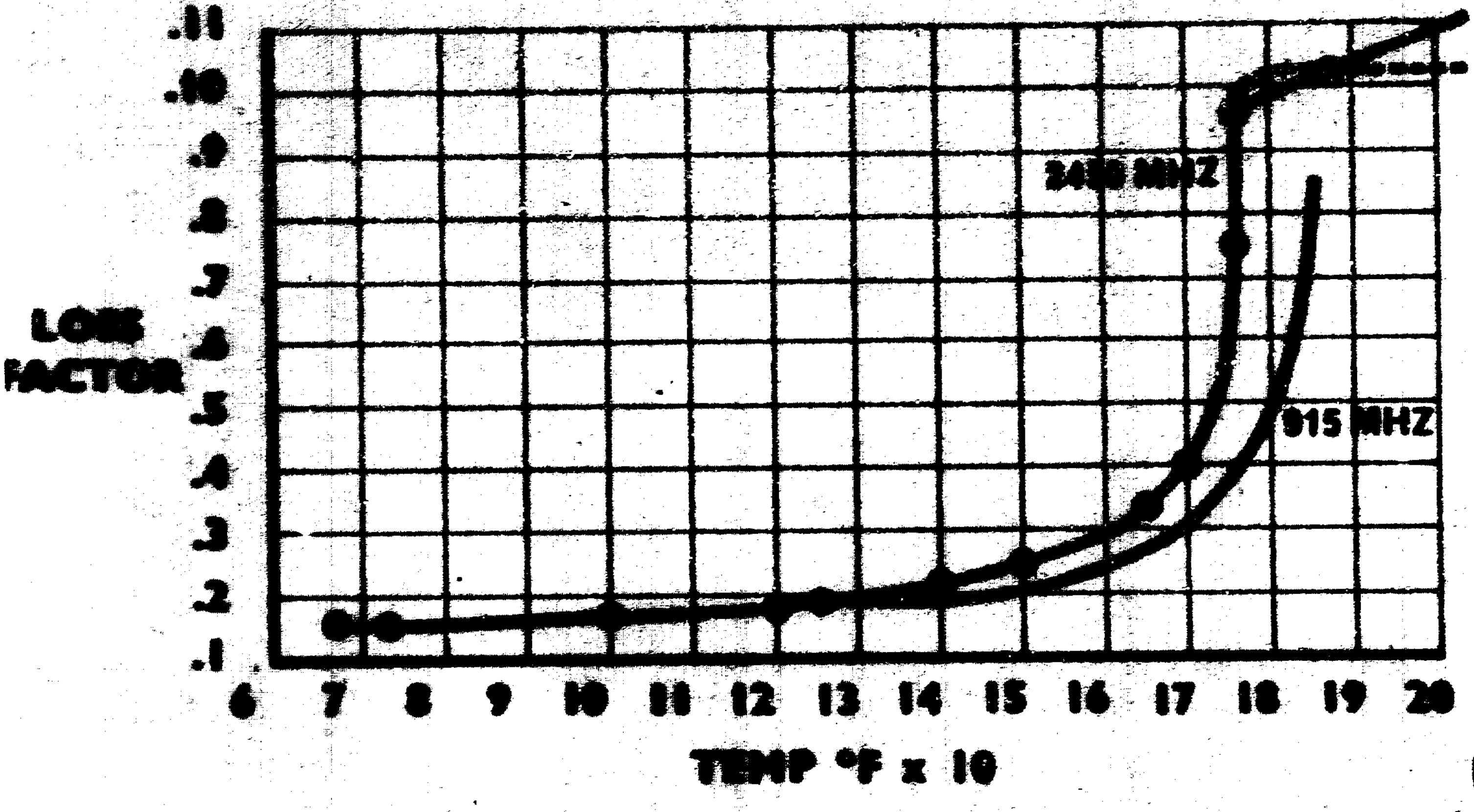
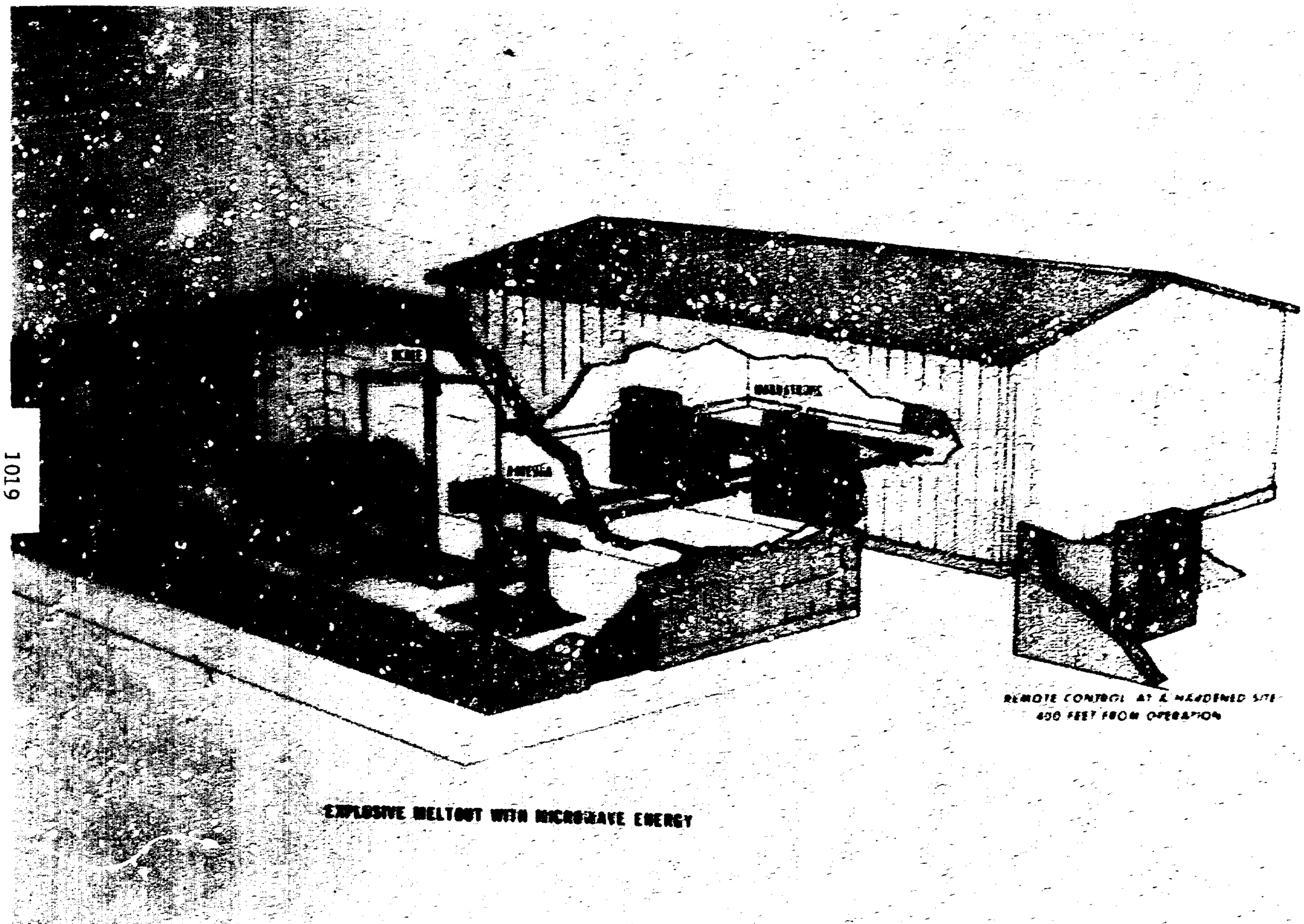


Fig 2

FIGURE 13

FIGURE 14

FIGURE 15



EXPLOSIVE MELTOUT WITH MICROWAVE ENERGY

MODELLING ENERGETIC MATERIALS AS SYSTEMS

by

Jean G. GOLIGER

French National Company for Propellant and Explosives (S.N.P.E.)

ABSTRACT

Energetic materials (gunpowder, high explosives, solid propellants, etc) are complex sets. They can be better understood if modelled as systems, i.e. as sets with interactive properties. The Energetic-Material as System (or EMS) approach leads to create a new concept, that of "energetic behavior". The "energetic behavior" of an explosive brings together all its decomposition properties (combustion, detonation, convective combustion, etc). The energetic behavior of an explosive forms the basis for assessing its hazards and performance.

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1 - INTRODUCTION - INADEQUACY OF TRADITIONNAL APPROACHES

This article describes the steps which led us to employ the notion of a system in modelling energetic materials, namely, to represent them as systems. Starting with the current state of knowledge which appears to be unsatisfactory, we shall show how the notion of system gradually took shape.

The term energetic materials which we employ denotes any type of explosive substance (gunpowder, propellants, explosives etc) in the condensed state.

Note also that the field of knowledge with which we are concerned here is essentially that of the decomposition properties of these materials. These properties are related to all possible decomposition modes of the material and their evolution (steady state conditions or sensitivity/stability).

Some energetic materials have been known for a long time; large bodies of information about them are often available. Furthermore, certain scientific disciplines, such as detonation science, have reached a very high level of specialization.

Nevertheless, the state of knowledge pertaining to decomposition properties is unsatisfactory. In many cases, the data available are sporadic, and not always consistent. Hence we only have a very incomplete view of the decomposition properties of these materials. It has also been observed that accidents shed light on unexpected properties, and that the knowledge of areas as fundamental as that of convective combustion is still in its inception.

This is because an energetic material is complex. Even the thorough knowledge of some of its properties at a high scientific level cannot substitute for an overall view. This fragmentary knowledge enables us neither to predict the real behavior of explosives in practical situations, nor to situate our information accurately in the overall scheme.

One example of this fragmentary approach is provided by the Encyclopedia of Explosives (Ref.1). This is a gigantic, outstanding work, a vast compilation of all information available about explosive substances. However, this enormous compilation is made without a consistent pre-established scheme interrelating the decomposition properties of explosive substances. One can guess the limitations of the work thus achieved, which only succeeds in providing "unstructured" knowledge.

Hence the field of energetic materials remains rather impenetrable and confused. The relevant training of researchers and engineers is a time-consuming, difficult matter. It is a field of activity of experts, and this often appears somewhat strange and unexciting to the interested layman.

Aware of this situation, we have attempted, over a period spanning several years, to develop a more synthetic method of information about energetic materials. Our efforts have succeeded and have led to fruitful applications. Some elements of this method are discussed here.

2 - GROUPING OF DECOMPOSITION PROPERTIES: ENERGETIC BEHAVIOR

We first tried to group the decomposition properties of an energetic material, and denoted this grouping by the expression "energetic behavior". We shall now show how we developed this notion.

2.1 Explosive behavior

Bibliographic research led us to an interesting work on this subject, the American manual AMCP 706.180 "Explosive Behavior" (Ref.2).

This work groups together the following:

detonation with its different variants (high and low velocity).
thermal explosion.

This work only deals with the most violent decomposition modes. Hence we felt that this grouping was incomplete. On the other hand, the work introduces a notion which we adopted, that of "Behavior".

2.2 Behavior versus properties

The characteristics of an energetic material are generally described under the term "properties". Thus we read of the "detonation properties" of an explosive. As we know, however, the real response of an energetic material to a stress from its environment is not a simple one.

Thus the term "property" appeared to us to be too static, too inadequate for a complete description of a material's characteristics. We therefore decided to use the term "behavior" when dealing with a set of properties, and reserved the term "property" to an elementary characteristic. Similarly, when attempting to describe the response of a material in a real situation, we have used the term "behavior": this notion refers to a situation, an environment, and corresponds more closely to the complex reality of possible responses.

Hence for detonation properties, we now use the expression "detonation behavior", which is itself part of the "explosive behavior" of the material.

2.3 Energetic behavior

Going a step further, we broadened the notion of "explosive behavior" and decided to group all the decomposition properties of the material under the term "Energetic Behavior".

This term thus includes:

- "stable" decomposition modes:
  - detonation,
  - parallel layer combustion,
- evolutive decomposition modes:
  - thermal explosion,
  - convective combustion,
  - transition toward detonation,
  - \- - - - - -
- sensitivity: i.e. ability of the material to adopt a given decomposition mode after a stress (deliberate or accidental).

ENERGETIC BEHAVIOR REFERS TO THE SET OF ALL THE DECOMPOSITION PROPERTIES OF A MATERIAL.

"Energetic behavior" includes "explosive behavior", to which the material's combustion properties have been added.

We now give a simple example of what is covered by the term energetic behavior for a solid propellant.

(a) Set of possible decomposition modes:

- detonation,
- thermal explosion,
- parallel layer combustion,
- pyrolysis.

with their specific characteristics. For example, for a detonation: detonation velocity, etc.

(b) Sensitivity: (to shock wave, to flame, ...).

3 - MODELLING EXPLOSIVE SUBSTANCES AS SYSTEMS

We shall now show how the notion of energetic behavior led us to model the material in the form of a system.

3.1 Overall behavior of the material

We felt that this new notion of "energetic behavior" would be useful in attempting to make a representation of the overall behavior of the material, as compared with the usual fragmentary view.

The representation of an energetic material thus includes two levels of description (figure 1).

- elementary properties: combustion rate, velocity of detonation etc,
- behavior: energetic, mechanical and other.

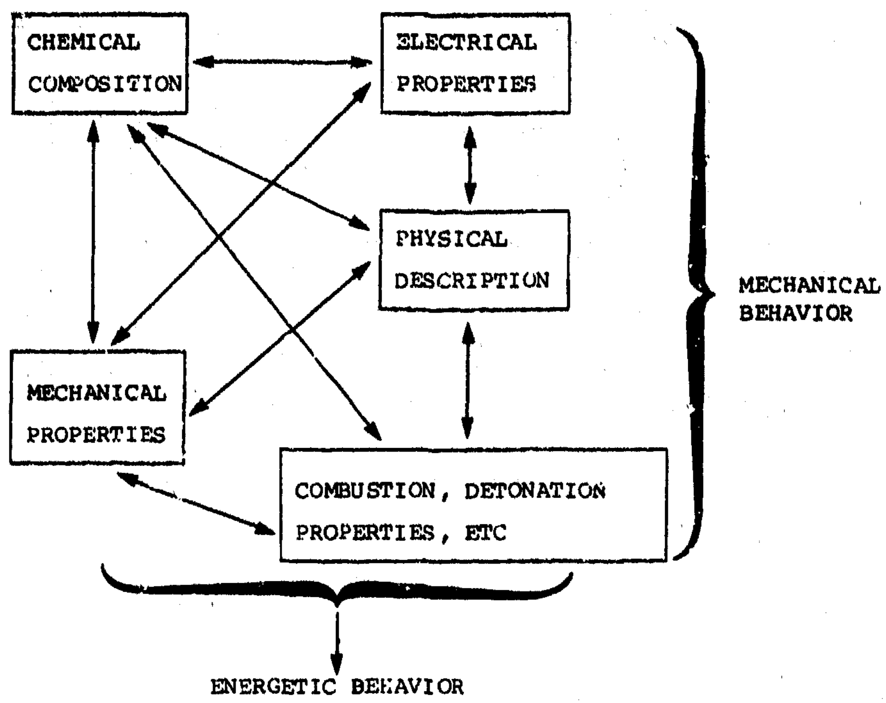

Figure n° 1 - PROPERTIES AND BEHAVIORS OF AN ENERGETIC MATERIAL

As we can see, energetic behavior is part of the general behavior of the material (figure 2).

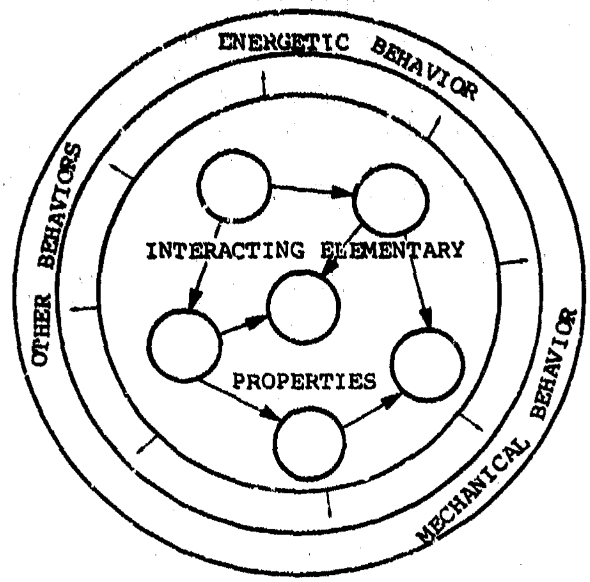

Figure n° 2 - REPRESENTATION OF AN ENERGETIC MATERIAL

THE ENERGETIC BEHAVIOR OF AN ENERGETIC MATERIAL IS THAT PART OF ITS OVERALL BEHAVIOR CONCERNED WITH ITS ENERGY LIBERATING FEATURES.

This overall view of an energetic material enables us to see the interactions of its properties clearly. Hence using this new approach, the combustion and detonation of a solid propellant are no longer independent properties, but different facets of a single characteristic: its energetic behavior. It is the existence of this characteristic that gives explosive substances their specificity. It is this energetic behavior which gives them their "raison d'être", and which is also the source of the hazards which they incur.

3.2 Behavior and system

Our analysis highlighted several ideas which we set forth below:

- the decomposition properties of an energetic material are not independent,
- they can be grouped within the notion of energetic behavior,
- energetic behavior is that part of the overall behavior of the material which is concerned with energy release.

At this point we can state the following: the manner in which we represent the material is merely a system* of which the elements are the elementary properties (figure 3) (*System : set of interacting elements organized to achieve a predetermined objective.)

This approach is over twenty years old in other fields (thermodynamics, biology etc). It provides a clear, synthetic view, upon the modelled sets. It in no way substitutes for specialized work, but supplements it.

The question arises as to how. We haveseen that the energetic behavior of explosive substances is complex, and that it is the result of the interaction of many elementary properties. The salient feature of the system approach is to proceed beyond spot analyses and to highlight the knowledge of these interactions.

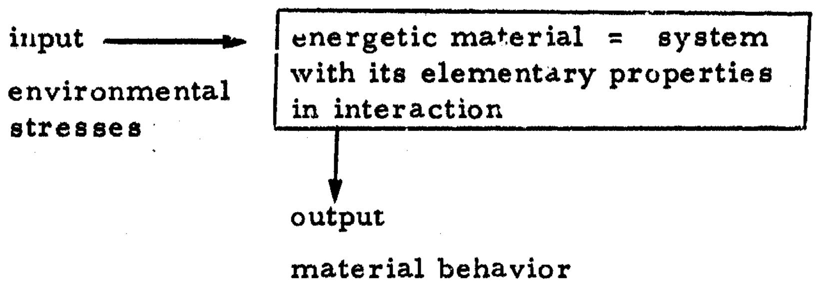

Figure 3 — Modelling an energetic material

3.3 Application of this model

In our view, this new approach offers potential applications in three areas: teaching and training, safety, and research.

With respect to the training of young engineers and scientists in explosive substances, the system approach renovates the teaching process. On the one hand, it becomes more attractive; on the

other, unification of the knowledge could lead to the development of certain multidisciplinary courses, rather than the intensification of certain disciplines to the extreme, which hyperspecialization is liable to make esoteric on the teaching level.

With respect to safety, we cannot neglect the tendency to consider the sets examined as systems. Hitherto, however, the possibility of placing explosive substances in systems was not seriously considered. One immediate application that can be described is the determination of (energetic) failure modes of the explosive substance itself.

It is a known fact that in the area of safety, it is hardly possible to make a risk analysis without knowing the failure modes of the elements. Modelling an energetic material as a system helps us to identify them for this material (we suggest the example of solid propellants) (figure 4).

input — aggression, normal environment, operational stress

system
solid propellants

output — functional mode: parallel layer combustion
failure modes: detonation, pyrolysis, thermal explosion, ...

Figure 4 — Energetic failure modes of a propellant

The energetic failure modes of a propellant are its non-functional decomposition modes.

To conclude, the system approach which we have applied to energetic materials provides us with a method which interlinks today's too fragmentary information. While it does not try to substitute for the traditional disciplines, this approach opens the way to a more synthetic interdisciplinary knowledge of explosive substances.

<u>Références</u>.

1 - Basil T. Fedoroff, "Encyclopedia of explosives and related items", Picatiny Arsenal, Dover, New Jersey, USA.

2 - "Principles of explosive behavior", April 1972, AMCP, 706.180, Headquarters US Army, Material Command.

THE FOAM-HEST

CALIBRATION TECHNIQUE

by

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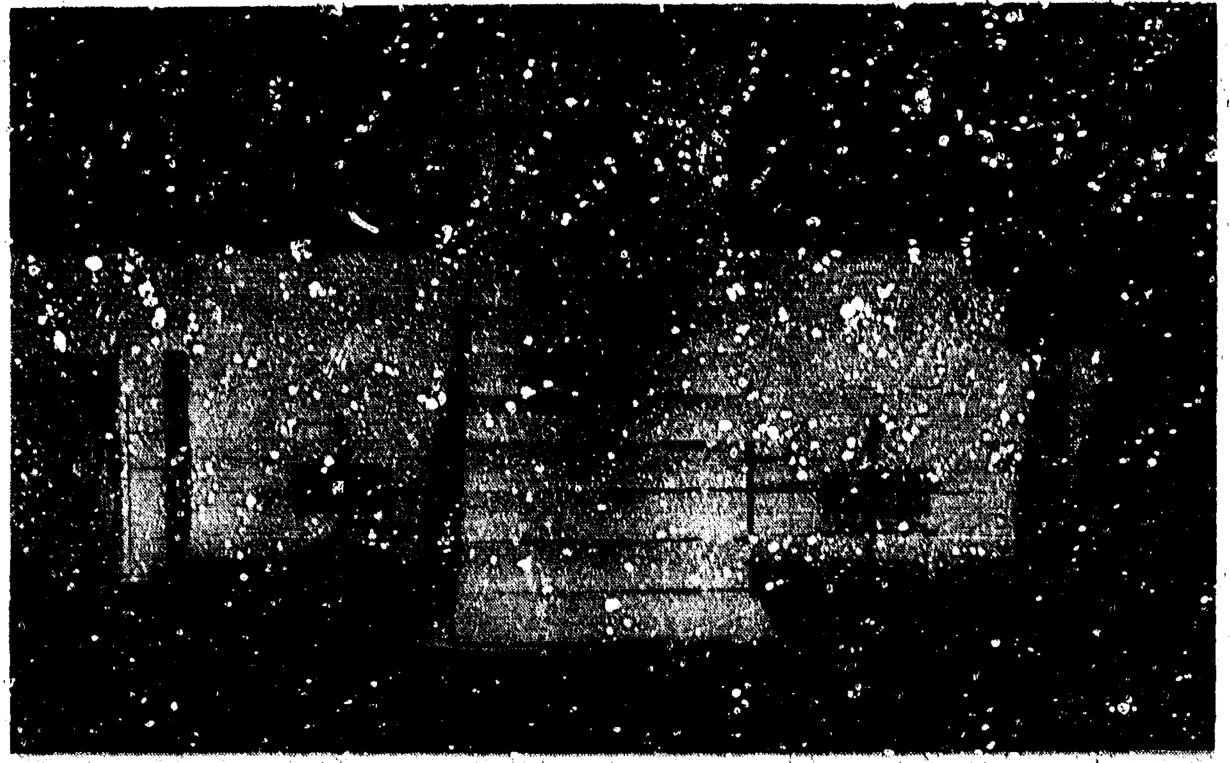
Sep 1980

GENERAL

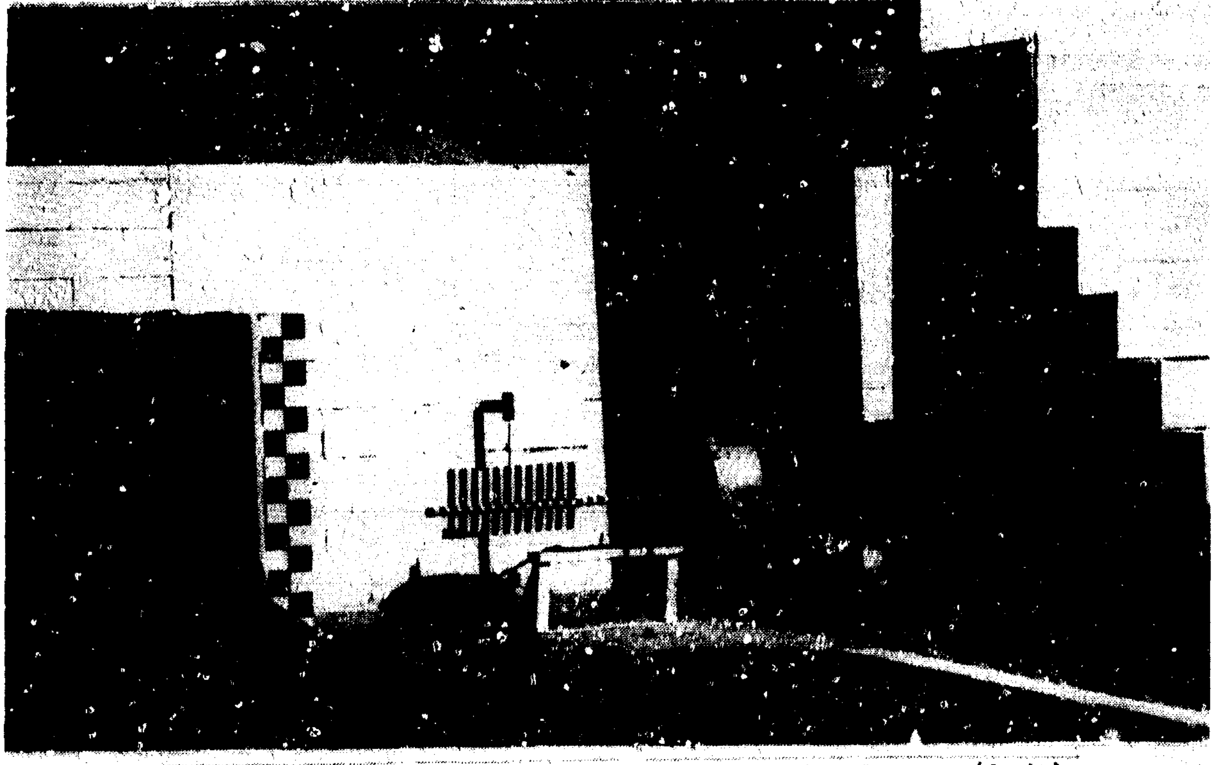
The Foam-HEST (High Explosive Simulation Technique) nuclear airblast simulator was described in detail in another paper before this symposium. In that paper, some of the variables inherent in the construction and functioning of that simulator were described. Some of the variables that affect the consequent simulation include the density, chemical make-up, and energy release characteristics of the explosive, the composition and density of the foam support material, the depth and density of overburden, and the method of explosive initiation and timing. Unfortunately, the ultimate simulation environment is extremely sensitive to many of these variables. In particular, the composition and relative densities and configurations of the foam and the explosive are critical to obtaining the desired environment. In the past, the so-called "fine-tuning" of the Foam-HEST system in preparation for a major simulation test was done by firing a series of relatively large field calibration experiments to "zero-in" on the desired high-pressure environment. These experiments were costly, time-consuming, and experimentally and scientifically rather unreproduceable. Also, as field experiments, they were fraught with the same safety problems as the major tests. To overcome these problems, the Air Force Weaspons Laboratory and the Civil Engineering Research Facility/ University of New Mexico (contractor) conceived and developed the Foam-HEST Calibrator (cylindrical calibrator, C^2).

FOAM-HEST CALIBRATOR

The Foam-HEST Calibrator is a laboratory-scale device designed to measure the resultant pressure-time environment produced by various foam/ explosive configurations. Figures 1, 2, and 3 show the device in detail.



a. Overall view, facing north retaining wall.



b. Detail of west cylinder and piston retrieval area (left).

Figure 1. Explosive-Foam Cylindrical Calibration (C^2) Facility.

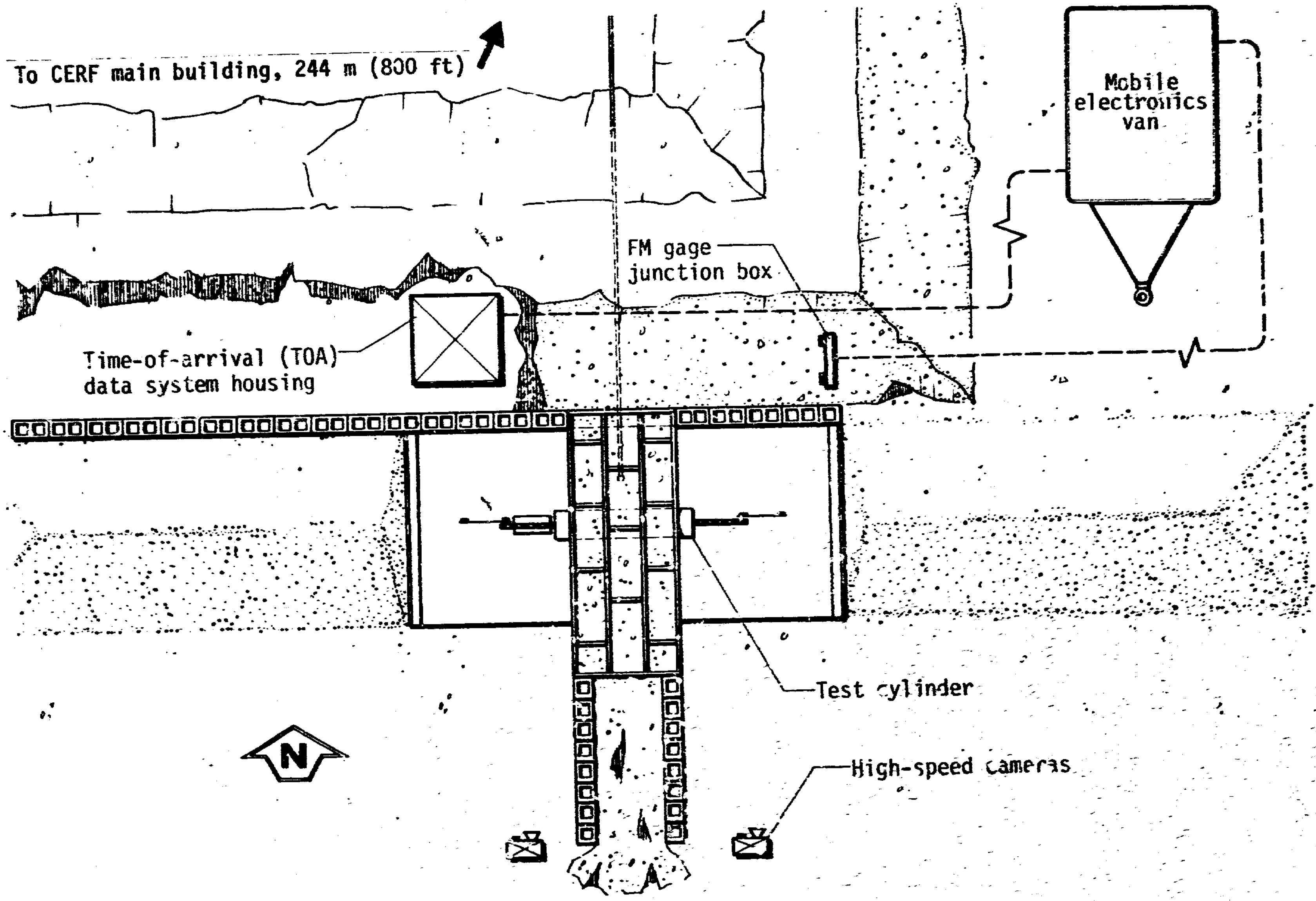


Figure 2. Explosive-Foam Cylindrical Calibration (C^2) Facility test-bed layout.

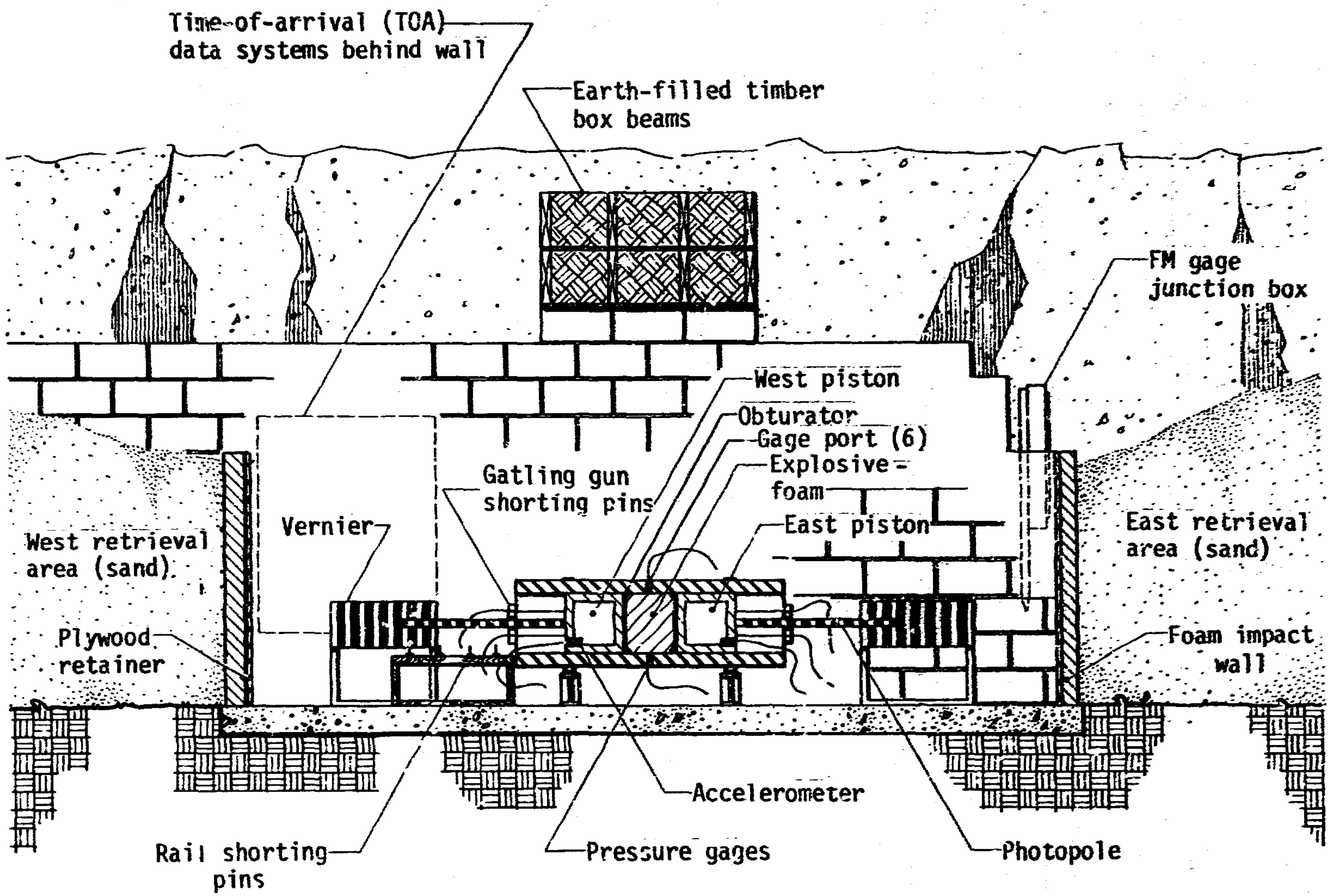
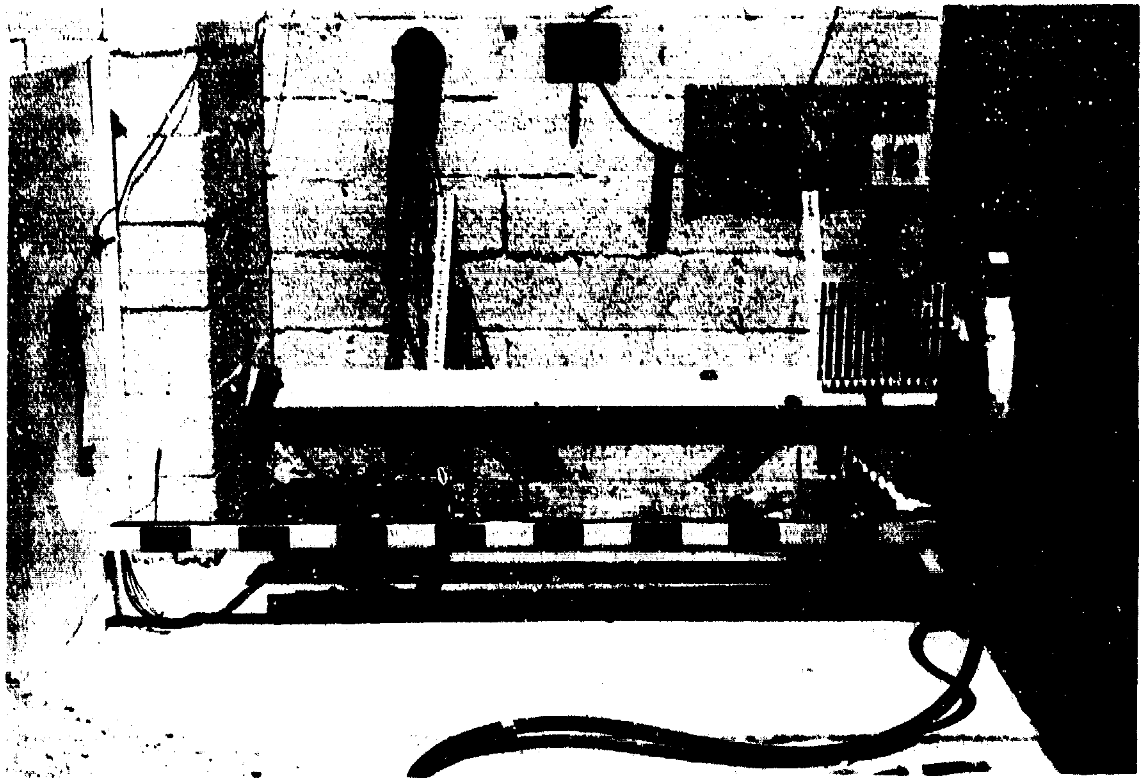


Figure 3. Explosive-Foam Cylindrical Calibration (C^2) Facility test-bed elevation.

The calibrator consists of a heavy-walled (76.2 mm thick) steel cylinder 330 mm in diameter. The tube is approximately 1.5 m long and made of high-strength 4140 steel. An explosive-foam charge is placed in the center of the cylinder and detonated by a high-voltage exploding-bridge wire (EBW) detonator. The detonator cable is fed into the cylinder through a small port in its side. The two open ends of the cylinder have been fitted with pistons constructed from a 305 mm long steel cylinder with an inset 50.8 mm thick faceplate. Within the cavity, behind the faceplate, a pole (photopole) is mounted on a threaded base plate for high speed photographic purposes. Sealing between the piston walls and cylinder walls, to prevent the early leakage of detonation products, is accomplished by use of a urethane plastic obturator.

INSTRUMENTATION

Several types of data are gathered in each experiment. Pressure measurements in the cylinder are made by pressure gages mounted in 31.75 mm diameter ports spaced around the cylinder midpoint. Gage faces are protected by debris shields. Piston displacement, post-detonation, is measured by high speed photography, time-of-arrival shorting pins, and double integration of piston-mounted accelerometers. All three methods give very consistent data. All gage outputs are transmitted by cable to nearby junction boxes and then, through buried cable, to a recording van located 30 m away. Figure 4 shows experimental configuration and the resulting piston ejection. Figures 5 and 6 illustrate some typical data from an experiment.



a. Detail of west cylinder, instrumentation, and piston retrieval area.

b. Piston retrieval area post test.

Figure 4. Explosive-Foam Cylindrical Calibration Facility

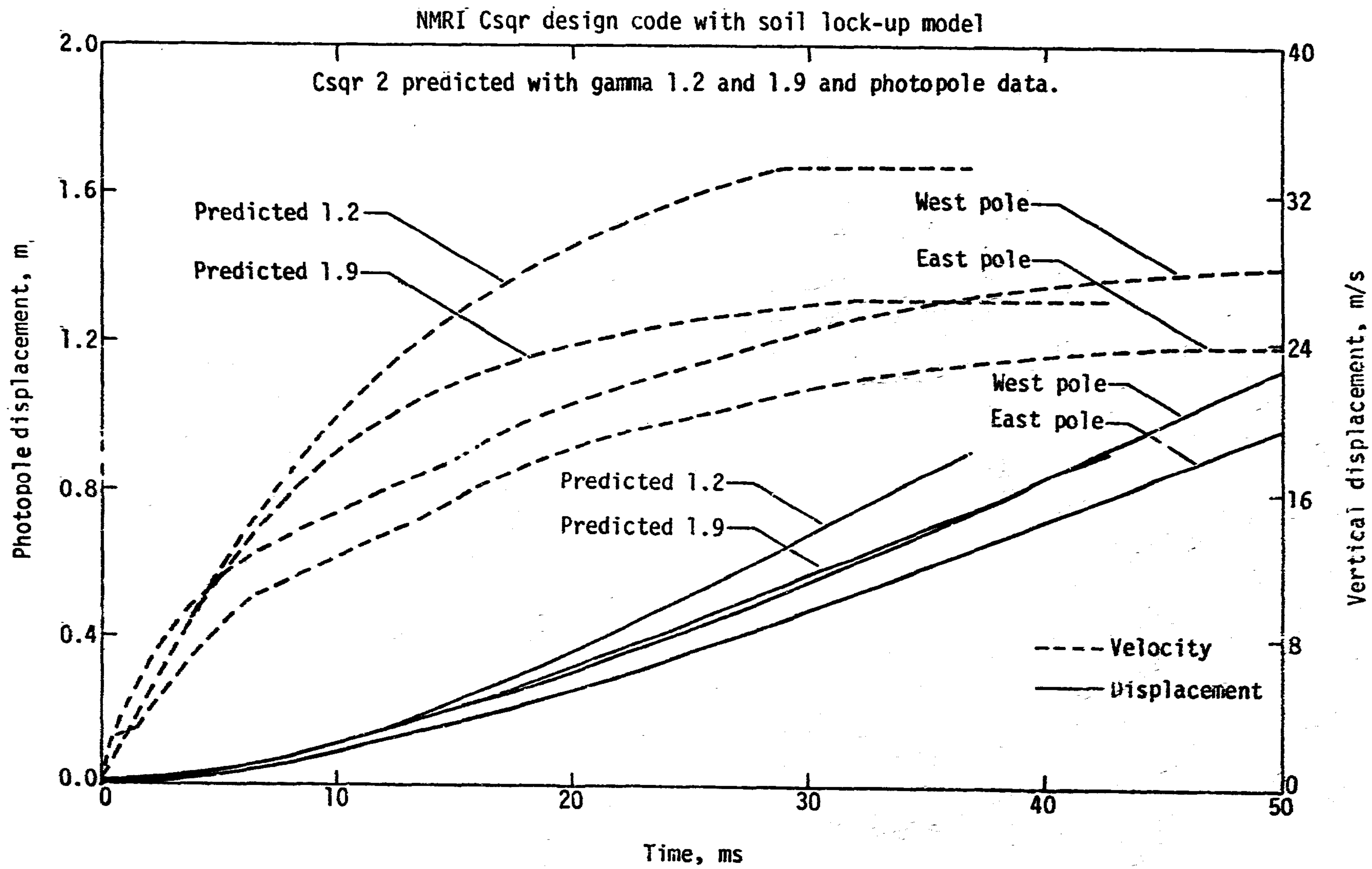


Figure 5. C^2 Proof Test 2 prediction versus observed piston motion.

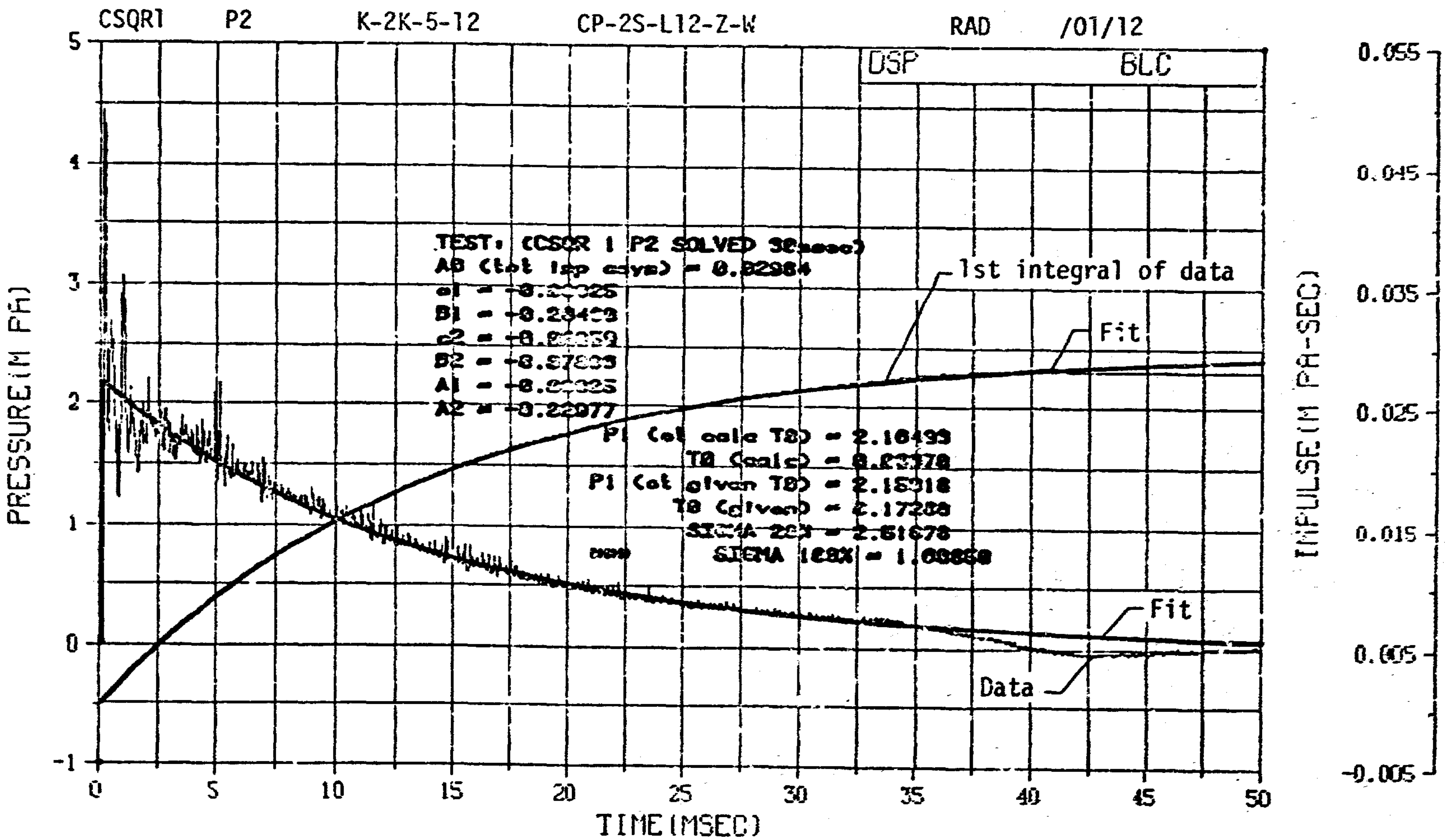


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Figure 6 C[2] Proof Test 1 data, corrected and analyzed--Pressure Gage 2 with double exponent peak-pressure-fit overlay.

SAFETY CONSIDERATIONS

To operate the Foam-HEST Calibrator in a safe manner, a number of precautions were taken during construction. The cylinder was constructed of high-strength steel, to withstand pressures of up to 14 MPa (in excess of 2,000 psi). The cylinder has been experimentally tested to over 20 MPa.

Because of the danger of flying debris in the event of a tube failure, a protection system was constructed. The north wall of the facility is a steel-reinforced, concrete-filled block retaining wall abutting a 3 m high earth berm. To the west, an extension of this wall provides blast protection for the time-of-arrival (TOA) data systems housing. This TOA enclosure is itself covered with earthfill for additional protection. The south wall is a steel-reinforced, concrete-filled block wall 2.4 m high but only 1.2 m wide with wing backs. Spanning the walls directly above the tube are two earth-filled timber box beams stacked vertically to provide 610 mm of earth and timber obstruction against fragments. (See figures 1, 2, and 3).

Since the pistons are expelled from the device during each experiment, it was necessary to construct retrieval areas approximately 2 m from the cylinder ends. After being expelled from the cylinder, the pistons lodge in the piston retrieval area. The energy of the piston is absorbed by its impacting a sand berm retained in place behind a foam-plywood retaining wall. The piston travels through the air, passes through the foam-plywood wall, and comes to rest a short distance into the sand. This system provides a method for retrieving the pistons with little or no damage.

As mentioned previously, data is gathered in a mobile electronics van located 30 m from the cylinder. The van is located northeast of the test area and behind a protective berm. The experiment is remotely detonated from this van after the area has been cleared of all personnel. Standard Air Force clearance, post-test, and hangfire procedures are followed in these experiments.

SUMMARY

A Foam-HEST Calibrator has been developed to reduce the time and cost of preparing for large-scale field HEST simulations. The development of this device has also resulted in enhancing the safety aspects of these test-firings relative to a field situation. High-strength steel, concrete block barriers, sand berms, and sand-filled box beams have been employed to minimize the dangers of flying debris. Data is gathered remotely behind a sand berm. Firing is accomplished remotely and standard explosives' safety countdowns and procedures are employed. This facility has maintained a perfect safety record in its two-year operational history. This has contributed to the Air Force Weapons Laboratory winning the Air Force Explosive Safety Award three years in a row (soon to be four).

UNIQUE EXPLOSIVE SAFETY PROBLEMS

ASSOCIATED WITH LARGE SCALE NUCLEAR AIRBLAST

AND

GROUND SHOCK SIMULATION TESTING

by

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and

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Sep 1980

UNIQUE EXPLOSIVE SAFETY PROBLEMS ASSOCIATED WITH LARGE SCALE NUCLEAR AIRBLAST AND GROUND SHOCK SIMULATION TESTING

During the past several years, the Civil Engineering Research Division of the Air Force Weapons Laboratory (AFWL) has been involved in the testing of conceptual models of missile shelters to the airblast and ground shock effects of nuclear weapons.

This work is done at remote locations by combinations of Air Force personnel and contractors. The testing includes the design and construction of large scale models, the application of instrumentation to the models, generating and measuring the airblast environment, and measuring motion of the near field test bed, and propagation of the ground shock to far field locations.

Each test requires the efforts of a large number of different disciplines working over a long period of time. Some of these overlap with the period when the explosives must be installed.

This paper deals with unique problems encountered in the process of fielding such a test.

For the testing of missile shelters, one of two kinds of simulators is usually used. The Dynamic Airblast Simulator (DABS) is used for small models where the target may be sensitive to dynamic pressure loads and to define dynamic pressure loads in cases where the calculation of these loads is infeasible, so that they can be simulated with another technique (see figure 1).

In this case, the explosive was a detonating cord. The design required an even distribution of a given amount over the back wall of the

DABS. This was done by calculating the amount to be hung on each hanger. Then wrapping it in a bundle and hoisting the bundle up to the hanger and tying it. This work was done by an Air Force crew consisting of three EOD NCO's, one officer who is qualified both in EOD and engineering and one ancient civilian who is experienced in explosives and engineering. This crew was highly disciplined and none of the usual explosive discipline problems were encountered. The technique used was to wrap the bundles in the explosive area, then transport the bundles to the site after site working hours and hang them on the wall. The usual warning signs were used and a guard was posted continuously until the firing date. The other workers such as instrumentation personnel continued their work on the model and other gages after the explosives were in place. One EOD NCO was left in charge of the explosive during working hours.

This test was the first in a series. One of the other tests utilized a contractor explosives crew. The other tests employed contractors not necessarily versed in explosives handling to emplace the explosives.

When dealing with contractors for explosive work there are two common situations. For the smaller DABS tests, a crew from the University of New Mexico, Civil Engineering Research Facility (CERF) was used to emplace explosives. This crew is regularly engaged in emplacing explosives of all kinds. They are well experienced and disciplined and are able to work with the other people with very few problems. In addition, the DABS type of experiment uses explosives that are separated by some distance from the main areas of work. This type of experiment is more expensive than the other

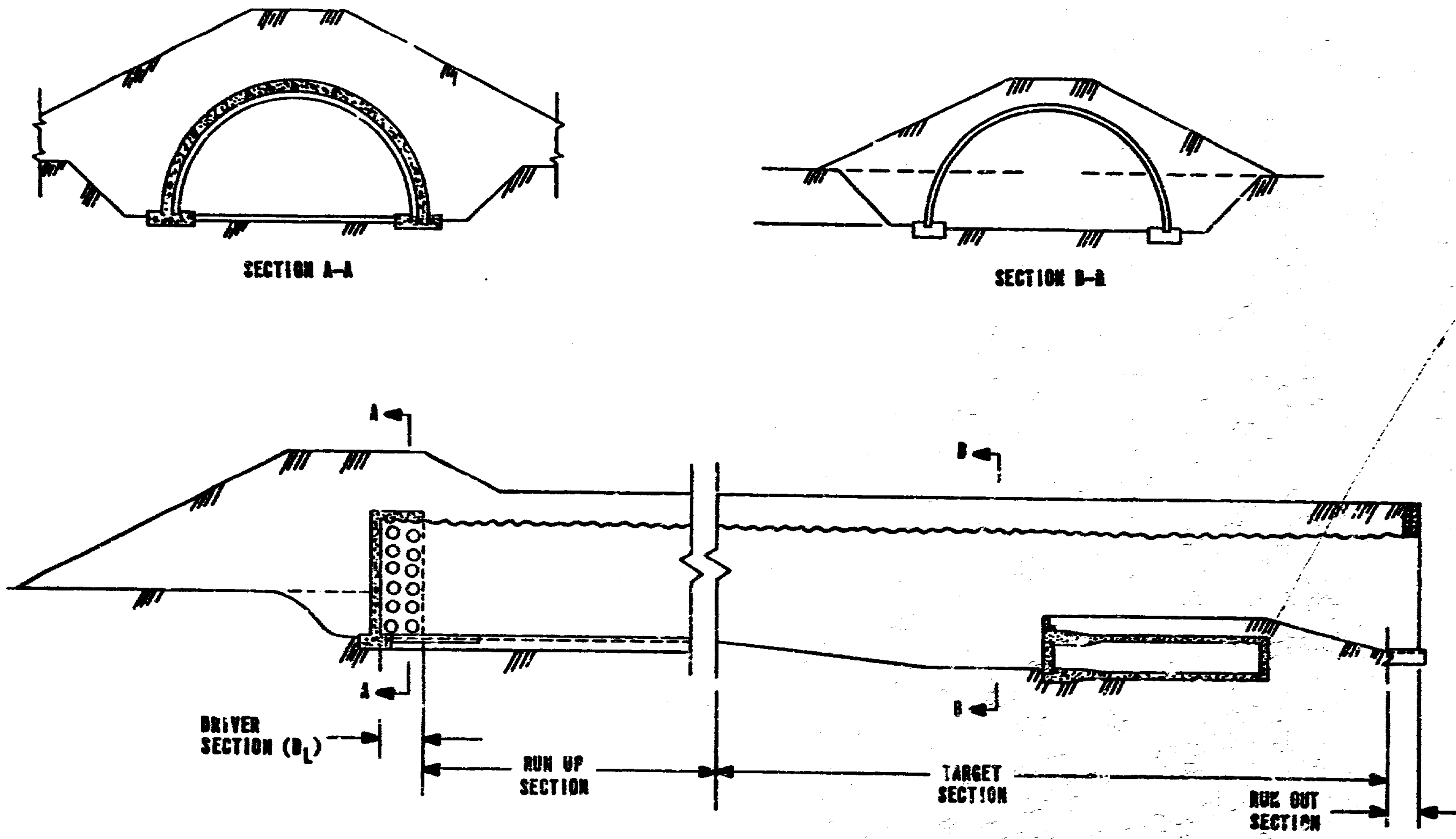

Figure 1 : Typical DABS

type and is used for smaller models where a high quality environment is required or where dynamic airblast loads on a structure cannot readily be calculated.

The other situation, where a High Explosive Simulation Technique (HEST) test is used requires much more attention. In this case, a contractor's crew of laborers is used to emplace large quantities of explosives and a strong adherence to the principles of system safety is required. The system safety aspects of a HEST test must be designed in as practical, constructable items. In order to understand how this is done, a basic explanation of a HEST is required.

A HEST is used to simulate some part of an airblast environment that has been calculated to be of interest to protective structures. These environments may be calculated from ideal nuclear waveforms or obtained experimentally by the DABS technique described earlier.

The HEST design is obtained by use of an Impulse Code called LOCKUP which yields the design parameters of depth of cavity, height of overburden, soil density, etc. The explosive design is made by use of, experimentally obtained, charge density curves for the configuration to be used.

This is translated into interleaved layers of explosive and foam so as to obtain the required pressure and shock wave velocity (see figure 2).

A recent test contained three underground structural models. Instrumentation crews were working in each model. It was necessary to supply power and air conditioning to these crews over the top of the HEST. It is not possible to perform the instrumentation functions and

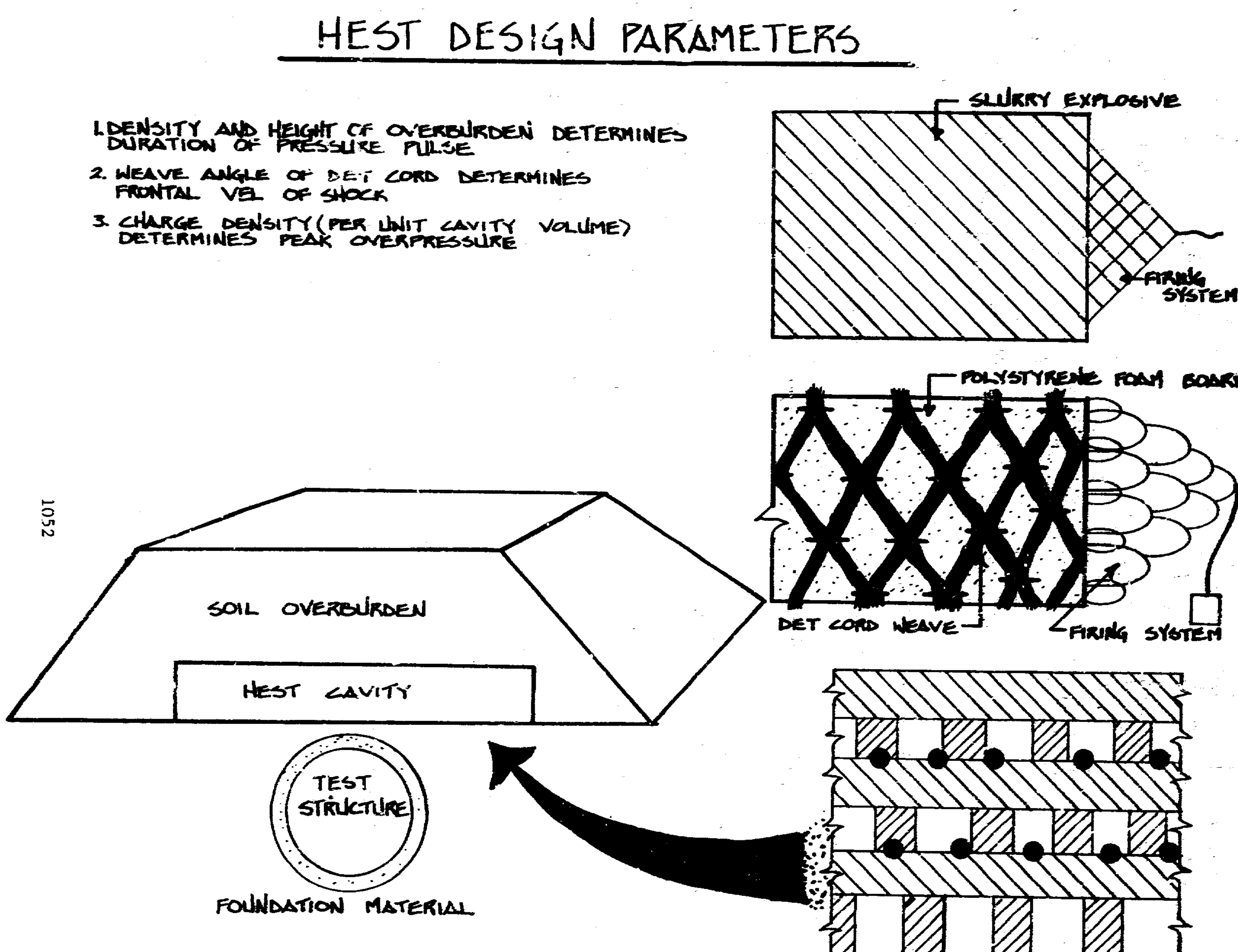

Figure 3: Typical HEST

explosive operations serially. This is one of the facets of this work that makes the explosive safety problems unique to this kind of R & D mission.

Techniques that are employed to cope with these unique problems include both recognition of the problem as an overall system safety problem and inclusion of items in the design that permit work to proceed on all aspects of the experiment.

The engineering design of the HEST has gone to the use of materials that can be emplaced quickly and safely. Cut-outs can be left until late time to allow access to underground models. These cut-outs are designed to be quickly and efficiently closed when the underground work is done.

The AFWL explosive safety officer is included in the discussions of techniques and procedures to be used in a test and his advice is followed.

Contractor personnel handling explosives and associated materials are briefed daily.

Instrumentation crews, survey crews and others who need to be in the area are briefed daily and coordinate on their activities relative to the explosive operation.

The cornerstone of the explosive safety program is to foster cooperation among all personnel concerned. The activities of the other disciplines are required for the test and must be allowed to proceed with as little interference as possible consistent with explosive safety requirements.

In this case, it was necessary for instrumentation and photographic crews to continue working in the underground structures until late time. During this time, it was necessary to provide for their passage back and forth

over the top of the HEST to the structures. Air conditioning pipes were temporarily emplaced over the HEST to provide relief from desert temperatures of over 100°F.

When the work inside the structures was completed, the high speed cameras were loaded with film and the photographers backed out. At this time, a crane was emplaced on top of the HEST overburden to lift the 3,000 lb doors into place.

When this work was completed, the construction crew removed the sandbags and foam boards that had been used to protect the explosives from the other activities and the laborers and carpenters came in to emplace the remaining portion of the explosives. After completion of the foam HEST, a front loader was used to emplace the remaining overburden.

After this point, other people were not required in the vicinity of the explosives. On test day, the instrumentation crews backed out of the near field bunkers one hour before test and the ordnance and safety crew checked out the firing system and attached the detonators to the firing point.

A review of some of the critical operational details is in order. (1) All personnel required to work in the vicinity of the explosives must be continuously aware of the nature and location of the explosive hazards. This includes many disciplines whose normal work is not related to explosives. (2) Continuous surveillance is required by explosives personnel over all activities in the vicinity of the explosives. (3) Precautionary measures must be taken such as banking around power units, air conditioning compressors and other required engines so that

accidents such as fuel spills, fires, etc. will not propagate to the explosives.

Probably the most important feature in the AFWL explosive safety program is to foster an attitude of cooperation among all personnel so that possible problems are anticipated, discussed, and dealt with before they become real full-fledged problems.

A NEW METHOD FOR PREDICTING LONG RANGE AIRBLAST OVERPRESSURES

by

Richard A. Lorenz
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ABSTRACT

A new airblast magnitude prediction method has been developed in an effort to reduce the impact of Naval Explosive exercises (both airdrops and Naval gunfire) on the neighboring communities surrounding the Bloodsworth Island Target Range in the Chesapeake Bay. This method uses measured or forecast upper air meteorological data to predict the airblast levels to be expected in the communities from explosions of any size. The method is applicable to both positive and negative sound velocity gradients and should be adaptable to other explosive operations.

Typical range operations were monitored in the surrounding communities and the airblast measurements were correlated with nearby weather data taken during the exercises. This paper will briefly describe the test program and the acquired data. The new airblast magnitude prediction method will be presented and justified.

INTRODUCTION

In an effort to reduce the impact of Naval airdrop and gunnery exercises on the neighboring communities, an extensive investigation was conducted in the area around the Bloodsworth Island target range in the Chesapeake Bay (see Fig. 1) between mid-September and mid-October 1978. The airblast levels and ground motions produced by typical Navy exercises were recorded. Rawinsonde measurements of the upper air meteorological conditions were taken while these operations were under way. A novel correlation was subsequently found between the meteorological conditions and the measured overpressure levels.

Under standard atmospheric conditions (little or no wind and negative temperature gradients) typical Naval gunfire and aerial bombing operations on Bloodsworth Island should pose no damage threat to the nearby eastern shore communities. However, when wind shears and/or positive temperature gradients exist, a phenomenon known as sound focusing can occur which drastically increases the airblast magnitudes propagated to large distances. A new method was developed which predicts the degree of sound focusing which can be expected from given weather conditions.

A detailed description of the test program, the data reduction techniques, and the search for a new sound focusing prediction method will be found elsewhere.[1] This paper will briefly describe the test program and the acquired data. The new airblast magnitude prediction method will be presented and justified.

TEST PROGRAM

Types of Data. Sound pressure level and ground motion recordings were taken for typical target range exercises. Two types of ordnance were used: (1) air-delivered Mk 82 bomb (110 kg TNT equivalent), which is the largest single munition item used on Bloodsworth Island; and (2) 5" Naval protectiles (4.1 kg TNT equivalent), which represent the most common type of gun firings from ships. Upper air weather soundings were made during all the test exercises. It was possible to monitor eight days of gunfire and eight days of bomb tests. A wide variety of weather conditions were experienced during the sixteen days of tests.

Monitoring Stations. Recording stations to monitor overpressure levels and ground motion were placed at sites that are representative of the local population centers and those areas most likely to be impacted by Range operations. The individual stations are listed in Table 1 and are shown in Figure 2. The intended impact area for the Mk 82 bombs was at the southern end of Bloodsworth Island, while the target area for Naval gunfire was located on the western side of the island. The stations which were fully instrumented were Deal Island, Top Point, and Crisfield. The bulk of the data analyzed comes from these three stations.

[1] Lorenz, R. A., and Berry, J. E., "An Investigation of the Sound Pressure Levels from the Navy Target Range on Bloodsworth Island", NSWC TR , in preparation

The systems which recorded pressure level histories had a range from 80 dB* to 145 dB and a flat frequency response from 1 Hz to 16 kHz (down 1 dB at the end points). The ground motion recording systems were sensitive to levels of motion from 0.25 mm/s to 25 mm/s in the 4Hz to 500 Hz frequency range for each of the three orthogonal components of motion.

Weather Stations. Upper air weather soundings were taken at three locations as shown in Figure 1. A mobile Navy weather team was stationed at the field headquarters and monitoring station on Deal Island, approximately 9 km ESE of Bloodsworth Island. Arrangements were made for soundings to be taken at the Naval Air Test Center, Patuxent River, approximately 34 km WNW of Bloodsworth Island. Regularly scheduled meteorological soundings were available from Wallops Island, approximately 55 km ESE of Bloodsworth Island.

Only three sets of parameters measured by the soundings are necessary for airblast prediction purposes. These are the temperature, the wind speed, and the wind direction as functions of altitude. They are combined to give the sound speed versus altitude profile for any desired azimuth angle. This sound speed profile sufficiently characterizes the sound focusing conditions for the given azimuth angle.

DATA ANALYSIS

Amount of Data. During the sixteen days of tests, recordings were taken on 59 Mk 82 bomb drops and 292 rounds of 5" Naval gunfire. Because of the multiple gains and backup systems used, a total of 43 recordings were normally taken by the six monitoring stations for each event. In addition, each of the gunfire recordings have two or three pulses (bow wave, shell explosion, and muzzle blast) that must be evaluated separately. Through a preliminary screening process, approximately 880 pressure records and 150 ground motion records were selected for digitization and detailed analysis.

A number of the pressure records were processed through a sound level meter to determine the effect of Flat, C-, B-, and A- weighting on the pressure signatures. Approximately 130 weighted pressure histories were digitized and analyzed. Further discussion on the effect of weighting the pressure histories will be found in Reference 1.

Bomb Data. Figure 3 is characteristic of the overpressure and ground motion records from Mk 82 bomb explosions. Rise times are relatively slow (tens of milliseconds). Multiple pulses are observed with the positive and negative peak pressures approximately equal. The ground motion sensor begins responding during airblast arrival, indicating that the ground motion was airblast-induced. No directly transmitted ground shock was ever positively identified in the test series. Two strong frequencies can typically be seen in the ground motion records, about 33 Hz and 10 Hz.

Sample digitized Mk 82 records are shown in Figure 4. The bulk of the airblast energy is typically concentrated in frequencies below 12 Hz. The 33 Hz frequency component is seen to be dominant in the two related ground motion records.

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*Instantaneous overpressures (p) in this paper are expressed in units of decibels (dB) defined by:

$$p(\mathrm{dB}) = 20 \log_{10} (p/p_0)$$

where p_0 = 20 micropascals.

A detailed examination of ground motion data was not made because all records indicate that the maximum velocities were two orders of magnitude below the documented 25 mm/sec threshold for structural damage.[2, 3, 4] It does not appear that ground motion from Mk 82 bombs contributes significantly to possible damage in the communities near the Bloodsworth Island target range.

Gunfire Data. Figure 5 shows the complex long-range signatures generated by Naval gunfire. The shell bow wave shown in Figure 5 is separated in time from the shell explosion, but usually the bow wave and the shell explosion signals arrive together and are not directly separable. The amplitude of the muzzle blast and its arrival time with respect to the shell explosion pulse varies with the position of the ship, number of guns fired, type of fire (single or multi-gun salvo), and the propellant charge. Generally, as shown in Figure 5, the amplitude of the muzzle blast was greater than that of the shell explosion, and its predominant oscillations were lower in frequency.

Sample digitized gunfire records are shown in Figure 6. The energy of the shell explosion was usually concentrated in frequencies below 100 Hz, while the energy in the muzzle blast is generally found below 30 Hz.

The ground motion resulting from 5" Naval gunfire is even less than that from Mk 82 bombs. Therefore, it does not appear that ground motion from Naval gunfire contributes significantly to possible damage in the communities near the Bloodsworth Island target range.

Damage Threshold Levels. Spectral analysis of the overpressure records shows that the blast energy is concentrated in frequencies below 12 Hz for Mk 82 bombs and below 25 to 50 Hz for 5" gunfire. Typical house structures can follow these frequencies[5] and will respond to the peak overpressure rather than to the impulse of the blast wave.

Complaints and damage reports were received on one day when Mk 82 bombs were being dropped while strong focusing conditions prevailed. The complaints and damage concerned loud noise, rattling windows, one broken window, and cracked plaster. Nearby sound overpressure levels were measured in the 125-135 dB range. Although the reported damage was minor and limited in area, the measured levels were considerably below the 134-140 dB threshold levels normally considered

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[2] Liu, T. K., Kinner, E. B., and Yegian, M. K., "Ground Vibrations". Sound and Vibration, 26-32, Oct 1974

[3] Nicholle, H. R., Johnson, C. F., and Duvall, W. I., "Blasting Vibrations and their Effects on Structures", Bureau of Mines Bulletin 656, 1971

[4] von Gierke, H. E., Chairman, "Guidelines for Preparing Environmental Impact Statements on Noise", CHABA WG 69 on Evaluation of Environmental Impact of Noise, Jun 1977

[5] "The Effects of Sonic Boom and Similar Impulsive Noise on Structures", NTID300.12, 31 Dec 1971

acceptable.[6, 7] Therefore, the peak overpressure level is believed to be the principal parameter related to damage and should be held below 130 dB.

Weather Data. Upper air weather soundings were scheduled for Deal Island and the Naval Air Test Center (NATC), Patuxent River at 0600, 1000, 1400, and 1800 EDT on test days, with an additional sounding at 2200 EDT during evening gunnery exercises. Wallops Island had regularly scheduled soundings at 0700 and 1900 EDT daily.

A total of 153 weather soundings were taken during the sixteen test days. Deal Island took 57 soundings, of which only 35 had useable wind data. NATC took 67 soundings, and Wallops Island provided 29 soundings.

The set of NATC soundings was used to represent the weather conditions in the Bloodsworth Island region. NATC had the most complete set of soundings made throughout the test days. Deal Island used the pibal method of visually tracking a balloon to obtain the wind data, while the other two stations used the LORAN-C navigational system. As a result the Deal Island wind data was excessively smoothed so that the weather data correlated very poorly with the measured airblast levels. Both NATC and Wallops Island weather data, however, correlated well with the measured airblast levels.

The wind speed and direction data represent one-minute averages during the rise of a standard balloon. This seems to be an appropriate averaging time to detect the significant wind trends. Most NATC wind data was taken using 15 second averaging intervals. In many cases the measured fluctuations were large and obscured the major trends. When these data were reworked numerically to give effective one-minute averaging intervals, the desired trends were obtained.

OVERPRESSURE AND WEATHER CORRELATIONS

Weather Parameter. Blast focusing occurs when the atmosphere acts like a lens to focus sound rays toward some point on the ground surface. According to ray tracing theory,[8, 9] this condition can come about when the speed of sound at any altitude exceeds the speed of sound at the ground surface. The weather data is, therefore, used to construct sound speed versus altitude profiles to estimate the degree of blast focusing that can occur.

At any altitude the total sound speed in any direction is equal to the temperature-dependent sound speed of the air plus the wind velocity component and is given by the equation:

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[6] "Sonic Boom Experiments at Edwards Air Force Base", Interim Report, NSBEQ-1-67, AD 655310, 28 Jul 1967

[7] Reed, J. W., "Guidelines for Environmental Impact Statements on Noise (Airblast)", Minutes of the Seventeenth Explosives Safety Seminar, 14-16 Sep 1976

[8] Cox, E. F., "Far Transmission of Air Blast Waves", Phys. Fluids 1, 95-101, Mar-Apr 1958

[9] Perkins, B., Jr., Lorrain, P. H., and Townsend, W. H., "Forecasting the Focus of Air Blasts due to Meteorological Conditions in the Lower Atmosphere", BRL Report No. 1118, Oct 1960

$$v = 331.4\sqrt{1 + T/273} - WS \cos (WD - \theta) \qquad (1)$$

where v = Total sound speed in the θ direction (m/s)

θ = Azimuth angle (deg), clockwise from true North

T = Temperature (deg C)

WS = Wind Speed (m/s)

WD = Wind Direction from which wind is blowing (deg), clockwise from true North

Direct application of ray tracing techniques were disappointing and inadequate. Many attempts were made to discover a useful relationship between the sound speed profiles and the measured pressure levels. The correlations tended to become worse as more details of the sound speed profile were included. Finally, a promising correlation was noticed when only the maximum sound speed difference and its altitude were combined. The parameter which eventually evolved to represent the weather conditions is related to η_{max} in Figure 7 and is given by the equation:

$$\beta = \arctan (\Delta v/4\ \Delta z)_{max} \qquad (2)$$

where β = Weather parameter (deg) for a given azimuthal direction

Δv = Sound speed difference (m/s) related to η_{max} in Figure 7

Δz = Height (km) for Δv above ground surface. If Δz is less than 0.3 km, it is reset to equal 0.3 km for this calculation.

Note that the weather parameter β depends only on the most important feature in the sound speed profile: the velocity difference which would have the maximum effect in standard ray tracing calculations. The usual ray tracing calculations fail because they are extremely sensitive to the detailed shape of the sound speed profile. Normal wind fluctuations can significantly alter the details of a sound speed profile within minutes after it is measured. A strong wind blowing at some altitude, however, can be expected to continue blowing for a considerable time and over a significant area. Therefore, if a sound speed profile is expected to represent the weather conditions over a large area for a period of time, only the major trends in the profile should be relied on in the first place.

The factor "4" in the expression for β helps to spread out the data points in the figures discussed below and to make the plotted data more linearly distributed. The 0.3 km limit on Δz was rather arbitrarily imposed to prevent gentle breezes near the ground surface from triggering erroneous severe focusing condition warnings.

Airblast Parameter. The airblast parameter $\bar{p}$ for an event is one-half the peak-to-peak pressure difference in the measured flat instantaneous overpressure versus time record. Half peak-to-peak is used because the measurements are sufficiently far-field that the peak positive and negative overpressures are approximately equal. In addition, baseline errors are eliminated and the results are more reproducible.

Correlations. Figure 8 shows the surface-detonated Mk 82 bomb pressure level data from Top Point and Crisfield plotted against the weather parameter β. These stations are 25 km from ground zero on two azimuthal directions 45 degrees apart. This comprises the largest set of unscaled data in this test series. A linear trend is noticeable despite the amount of scatter. The upper line in Figure 8 was fit to the data as a practical upper bound. It represents the maximum expected overpressure level for given weather conditions. A practical minimum expected overpressure level line which bounded the bulk of the data was chosen to be 19 dB below the maximum expected line.

The available pressure level data from the multi-ton shots[10, 11, 12] listed in Table 2 were scaled to Mk 82 bombs at 25 km at sea level (102 kPa). The resulting values are plotted as x's in Figure 9 along with the Mk 82 data from Figure 8. The scaling laws relating a reference level (subscript o) and a level at altitude (subscript z) are:

$$p_o = p_z \left(\frac{P_o}{P_z}\right) \quad \text{and} \quad \lambda_o = \lambda_z \left(\frac{P_z}{P_o}\right)^{1/3} \qquad (3)$$

where p is the instantaneous overpressure, P is the ambient pressure, λ equals $R/W^{1/3}$, R is the distance from the explosion, and W is the TNT equivalent weight of the explosive. Assuming a power decay law of the form $p = \text{const}/\lambda^{\alpha}$, the scaled overpressures become

$$\frac{p_o}{p_z} = \left(\frac{P_o}{P_z}\right)^{1-\frac{\alpha}{3}} \times \left(\frac{W_o}{W_z}\right)^{\alpha/3} \times \left(\frac{R_z}{R_o}\right)^{\alpha} \qquad (4)$$

where α = 1.4 was used. This value for α makes the scaled multi-ton data fit best with the Mk 82 data. For example, using a value of 1.2 for α would raise the x's in Figure 9 by an average of 3 to 4 dB.

The maximum and minimum lines from Figure 8 are also drawn on Figure 9 and do a respectable job of containing the bulk of the multi-ton data points. The median expected overpressure line is 6.5 dB below the maximum expected line, as is shown in Figure 9. Therefore, because of normal weather fluctuations, half of the data in a series of shots is expected to lie above the median curve and

[10] Reed, J. W., "Project MIDDLE GUST Blast Predictions and Microbarograph Measurements", Proceedings of the MIXED COMPANY/MIDDLE GUST Results Meeting 13-15 March 1973, Vol 1, DNA 3151P1, 1 May 1973

[11] Reed, J. W., "DICE THROW Off-site Blast Predictions and Measurements", Proceedings of the DICE THROW Symposium 21-23 June 1977, DNA 4377P-2, Jul 1977

[12] Reed, J. W., "Long Range Predictions and Measurements, MISERS BLUFF, Phase II", Proceedings of the MISERS BLUFF Phase II Results Symposium 27-29 March 1979, Vol. I, POR 7013-1, 26 Sep 1979

the other half below. Since (it will be shown later) the distribution of data points above the median line is different from that below the median line, the average expected overpressure line lies 2.2 dB below the median expected line.

Figure 10 shows the lines of Figure 9 scaled from 25 km to 9.0 km (+12.4 dB) and superimposed on the Deal Island Mk 82 data. These lines represent the trend of the data reasonably well despite the greater scatter in the Deal Island data.

Figure 11 shows a lognormal plot of the differences of the Mk 82 bomb data in Figures 9 and 10 from the maximum expected lines. From this figure it is seen that the median (50 percent) line lies 6.5 dB below the maximum expected line. It is also apparent that the distribution of data above the median line is different from that below the median line. Why this should occur has not been investigated.

Figure 12 shows the lines of Figure 9 scaled from 25 km to 12 km and from 110 kg to 4.1 kg (-4.3 dB). The dots (•) represent the unscaled Deal Island pressure level data from 5" Naval gun shells detonating at impact on Bloodsworth Island. The x's represent the Top Point shell explosion data scaled from 28 km to 12 km (+10 dB). Each vertical bar connects the maximum, median, and minimum overpressure levels from a series of 5" shells closely spaced in time. The lines bracket the data and represent the trend quite well. The single disagreeing set of data occurred on a very blustery day; the actual atmospheric conditions had probably changed drastically from the time the sound speed profile had been measured.

Some difficulty was experienced in determining an acceptable equivalent weight for the muzzle blast of 5"/38 caliber and 5"/54 caliber Naval guns. A value can be derived from the Deal Island and Top Point muzzle blast data plotted on Figure 13. The dots (•) represent the unscaled Deal Island muzzle blast data measured at a distance of 21 km from a typical ship position. The x's represent the corresponding Top Point data scaled from 37 km to 21 km (+7 dB). Each vertical bar connects the maximum, median, and minimum overpressure levels from a series of 5" gun firings closely spaced in time. Then a set of lines of the "correct" slope were selected which resulted in a practical upper bound for the muzzle blast data. Note how well they bracket the data and represent the trend. By scaling these lines back to those in Figure 9, a value of 30 kg TNT was found to represent the muzzle blast assuming a nominal ship standoff of 21 km from the Deal Island monitoring station. Both Deal Island and Top Point are situated within 10 or 15 degrees from most possible direct lines of fire from the ships. Muzzle blast is a strongly directional phenomenon, but the value of 30 kg TNT can be used as a practical upper bound for the muzzle blast from typical Naval 5" gunfire on the Bloodsworth Island range.

Scaling Considerations. Eventually someone is going to ask why the sound speed profile is never scaled. The general scaling rules do indicate that the parameter β should be a function of $\left(\frac{\Delta v}{4\Delta z} \times W^{1/3}\right)$. If β were made dependent on the explosive weight W, the multi-ton data in Figure 9 would be pinned beyond $\beta = \pm 80$ degrees. This is not the natural (statistically normal) distribution that should be expected from the multi-ton data. Indeed, the multi-ton data looks very well-distributed as it appears in Figure 9. There has been no time

to pursue this question adequately, but the method as presented in this paper appears to be consistent when the explosive weight and distances are scaled, but not the sound speed profile.

Focal Point Approximation. Many different approaches were tried in the attempt to find a correlation between the weather data and the pressure level data. While working with the ray tracing equations in Reference 9, an approximation was found which greatly simplifies the determination of focal points, i.e., locations on the ground surface at which sound rays are concentrated by the lens effect of the atmosphere. The standard ray tracing methods locate focal points either by finding regions where an unusually large number of ray paths touch the ground [8,9] or by finding places where the rays' touchdown points decrease in distance from the source and then begin to increase as the rays' initial angles of departure are gradually increased.[13] Both of these methods require that a large number of ray paths be calculated in order to ensure that no focal point is missed. With the new approximation, focal points are calculated in a straightforward manner and only one ray path calculation is required for each possible focal point. The approximation is discussed in detail in Appendix A. It is mentioned in this paper because it is a result of the investigation being reported and in order to make it available to those who might find it useful.

Discussion. Any attempts to correlate the pressure level data with the fine details of the sound speed profiles are destined to fail because of wind fluctuations. To make matters worse for this particular investigation, the weather data was taken only once every four hours and 34 km away across the Chesapeake Bay from ground zero. In addition the locations of the ships, shell hits, and bomb hits are not precisely known. In spite of all the above, this section demonstrates that a correlation apparently does exist between the overpressure level and weather data for explosive charge weights ranging from 4.1 kg to 4.5×10^5 kg. This correlation must be related to some fundamental large-scale phenomenon which controls the long range airblast propagation. Otherwise any trend would have been masked by all of the above problems. The data scatter certainly prevented the derivation of too elaborate a prediction method, but the one reported below is believed to be realistic and should give useful results, especially for the Bloodsworth Island area.

THE NEW PREDICTION METHOD

The correlation discussed in the previous section quantitatively relates the following four parameters: W, the surface-detonated TNT equivalent explosive weight; R, the distance from the explosive to the point of interest; $\bar{p}$, one-half the peak-to-peak pressure difference in the instantaneous overpressure signature at the point of interest; and β, the weather parameter which represents focusing conditions between the explosion source and the point of interest. This means that if any three of these parameters are known, the fourth can be solved for.

[13] Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual" NSWC/DL TR-3786, Mar 1978

In this section a method will be given to determine $\bar{p}$ when W, R, and β are known.

To determine the weather parameter β, first generate the sound speed versus altitude profile along the azimuth of interest using Equation 1. Then for each altitude level, calculate $\tan \eta = \Delta v/\Delta z$ as indicated in Figure 7. For altitudes below 0.3 km, calculate $\tan \eta = \Delta v/0.3$ km. Finally calculate β using Equation 2 and the maximum value of $\tan \eta$.

Figures 8 and 9 show that the maximum expected overpressure level $\bar{p}_{max} = 111.3 + \beta/6$ decibels for W = 110 kg, R = 25 km, and ambient pressure P_o = 102 kPa. Using Equation 4 with $\alpha = 1.4$ to scale these conditions, the maximum expected overpressure level $\bar{p}_{max}$ in decibels is given by

$$\bar{p}_{max} = 111.3 + \beta/6 + 20 \log_{10}\left[\left(\frac{P_o}{102 \text{ kPa}}\right)^{0.533}\left(\frac{W}{110 \text{ kg}}\right)^{0.467}\left(\frac{25 \text{ km}}{R}\right)^{1.4}\right] \quad (5a)$$

$$= 110.0 + \beta/6 + 20 \log_{10}\left[P_o^{0.533}\, W^{0.467}/R^{1.4}\right] \quad (5b)$$

where $\bar{p}_{max}$ = maximum expected overpressure level (dB)

β = Weather parameter (deg)

P_o = Ambient pressure (kPa)

W = Explosive weight (kg), TNT equivalent surface detonation

R = Distance from explosion (km)

The median expected overpressure level is obtained by subtracting 6.5 dB from Equation 5. For the average expected overpressure level, subtract 8.7 dB from Equation 5. For an airburst, subtract 2.8 dB from Equation 5 (surface reflection factor of 2).

It is recommended that the maximum expected overpressure level $\bar{p}_{max}$ be kept less than 130 dB.

CONCLUSIONS

The measured ground motion does not contribute significantly to possible damage in the communities near the Bloodsworth Island target range. The peak overpressure level is believed to be the principal parameter related to damage and should be held below 130 dB.

The overpressure prediction method described in this paper has substantial advantages over other methods:

- Overpressure levels can be predicted if the explosive weight is known; or the maximum allowable charge weight can be determined for a limiting overpressure level.

- The expected variation of the actual overpressure levels from the predicted levels is known.

- Negative gradient sound speed profiles (no velocity greater than that at ground level) are processed in the same straightforward manner. Other methods cannot quantitatively evaluate negative gradient profiles.

- A single positive gradient at ground level will automatically be detected and evaluated. Ray tracing methods will not calculate focal points for single positive gradients.

- The new method is insensitive to the details of the sound speed profile.

- The calculational procedure is simple.

- The new method should be adaptable to other explosion operations and ranges.

The new prediction method is based on long range overpressure measurements where $R/W^{1/3} > 1900$ m/kg$^{1/3}$ and where the peak positive and negative overpressures are approximately equal. The minimum scaled distance at which this method is still valid has not been determined.

This paper has attempted to demonstrate that it is possible to easily and more reliably quantify the focusing effects of a wider variety of weather conditions than has previously been possible. The new method should provide meaningful predictions for the long range overpressure levels to be expected under given weather conditions.

ACKNOWLEDGEMENTS

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13. Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual", NSWC/DL TR-3786, Mar 1978

TABLE 1

Monitoring Stations

Station	Mk 82 Bombs Distance*/Azimuth**	5" Gunfire Distance*/Azimuth**	Record Types
Bishops Head	9.1 km/10^o	6.1 km/40^o	peak pressure
Deal Island	9.0 km/80^o	12 km/100^o	pressure history ground motion
Top Point	25 km/90^o	28 km/95^o	pressure history ground motion
Fairmount	23 km/100^o	27 km/105^o	peak pressure
Kingston	29 km/105^o	33 km/110^o	pressure history
Crisfield	25 km/135^o	30 km/135^o	pressure history ground notion

* Distance from expected impact area.

** Azimuth angle clockwise from true North.

TABLE 2

Multi-ton Shots

MIDDLE GUST B	100 Ton TNT
MIDDLE GUST C	100 Ton TNT
PRE-DICE THROW I	100 Ton TNT
PRE-DICE THROW II	120 Ton ANFO
DICE THROW	600 Ton ANFO
MISERS BLUFF I	120 Ton ANFO
MISERS BLUFF II	720 Ton ANFO

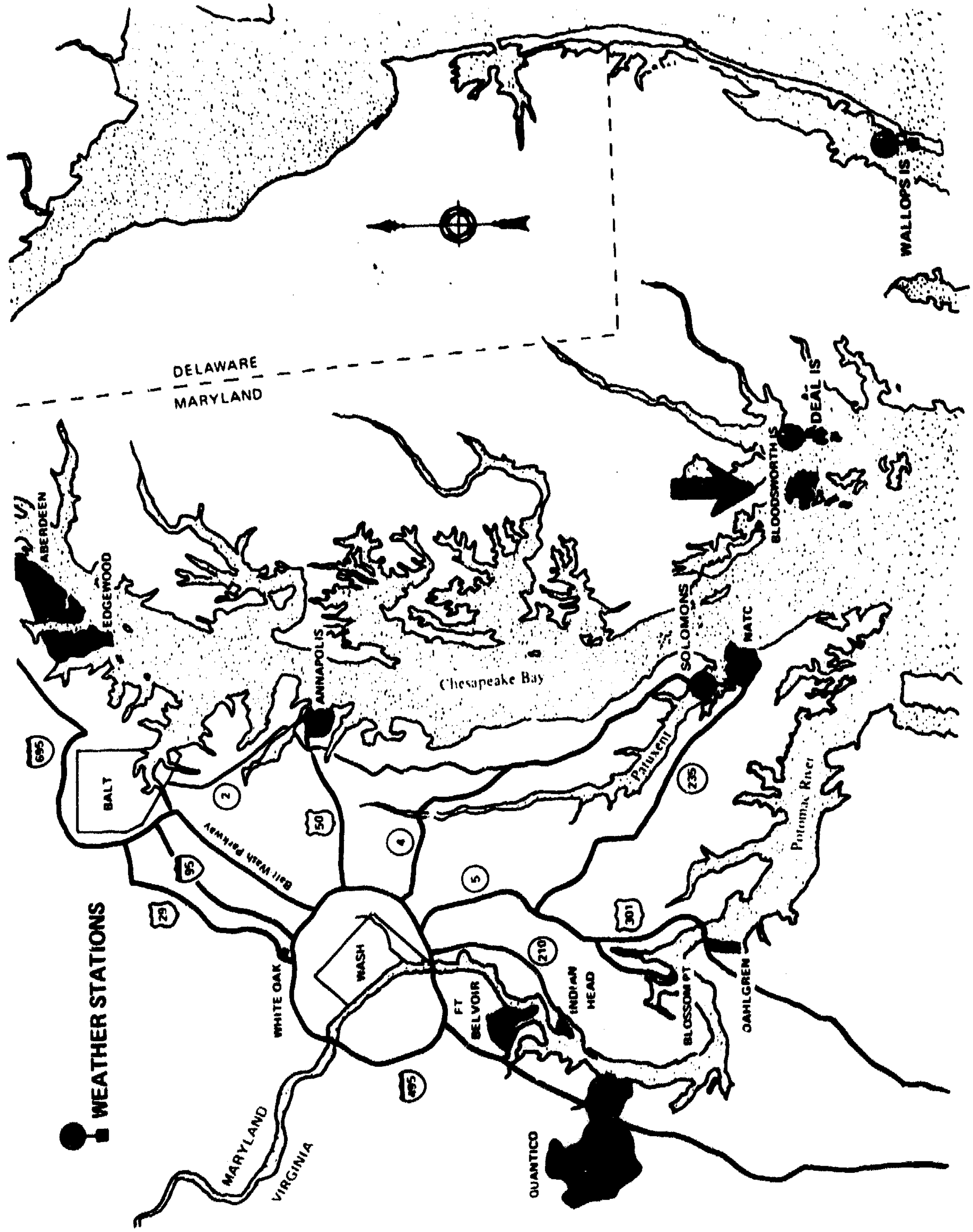

FIGURE 1. CHESAPEAKE BAY AREA

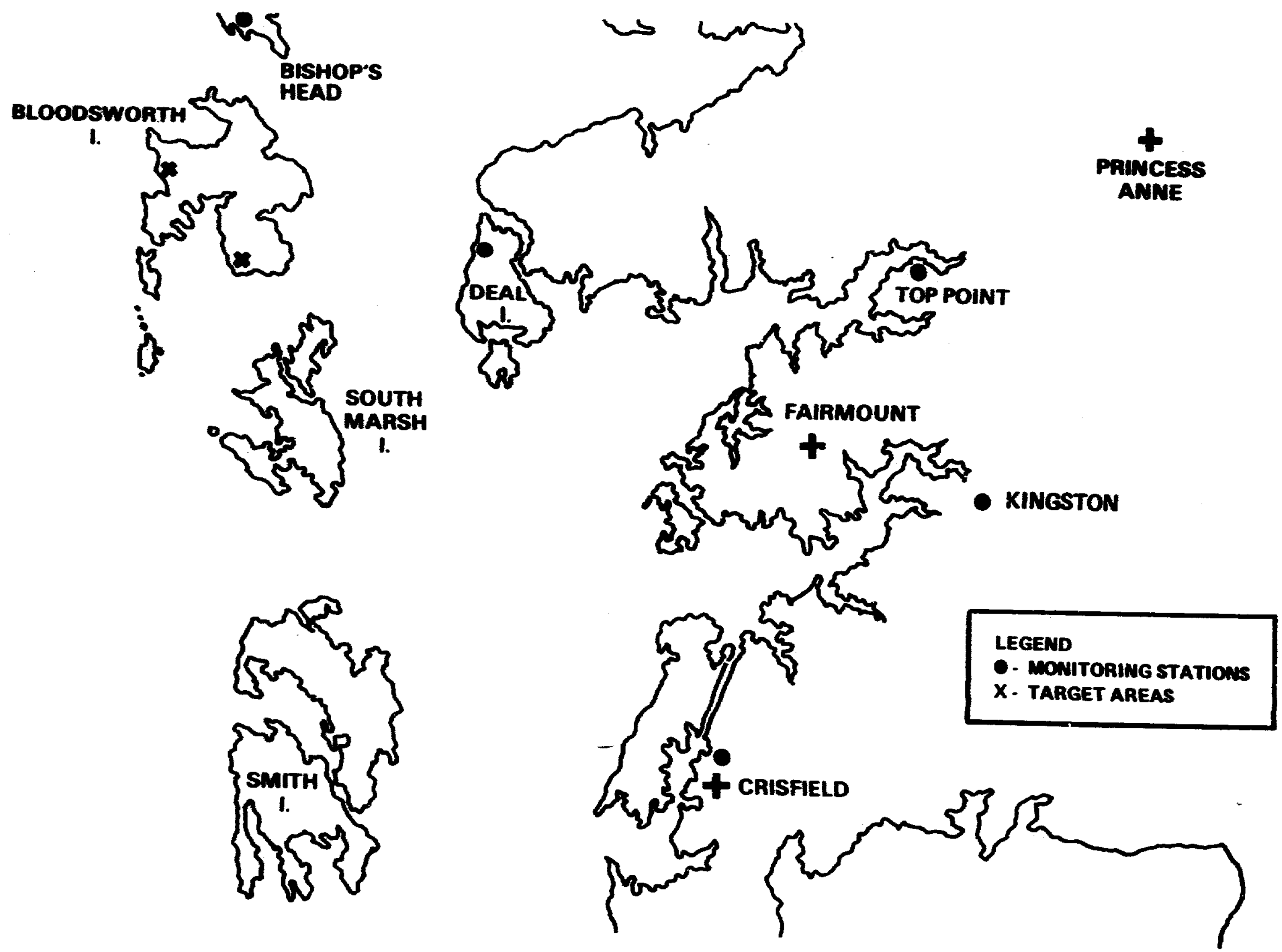

FIGURE 2. MONITORING STATIONS

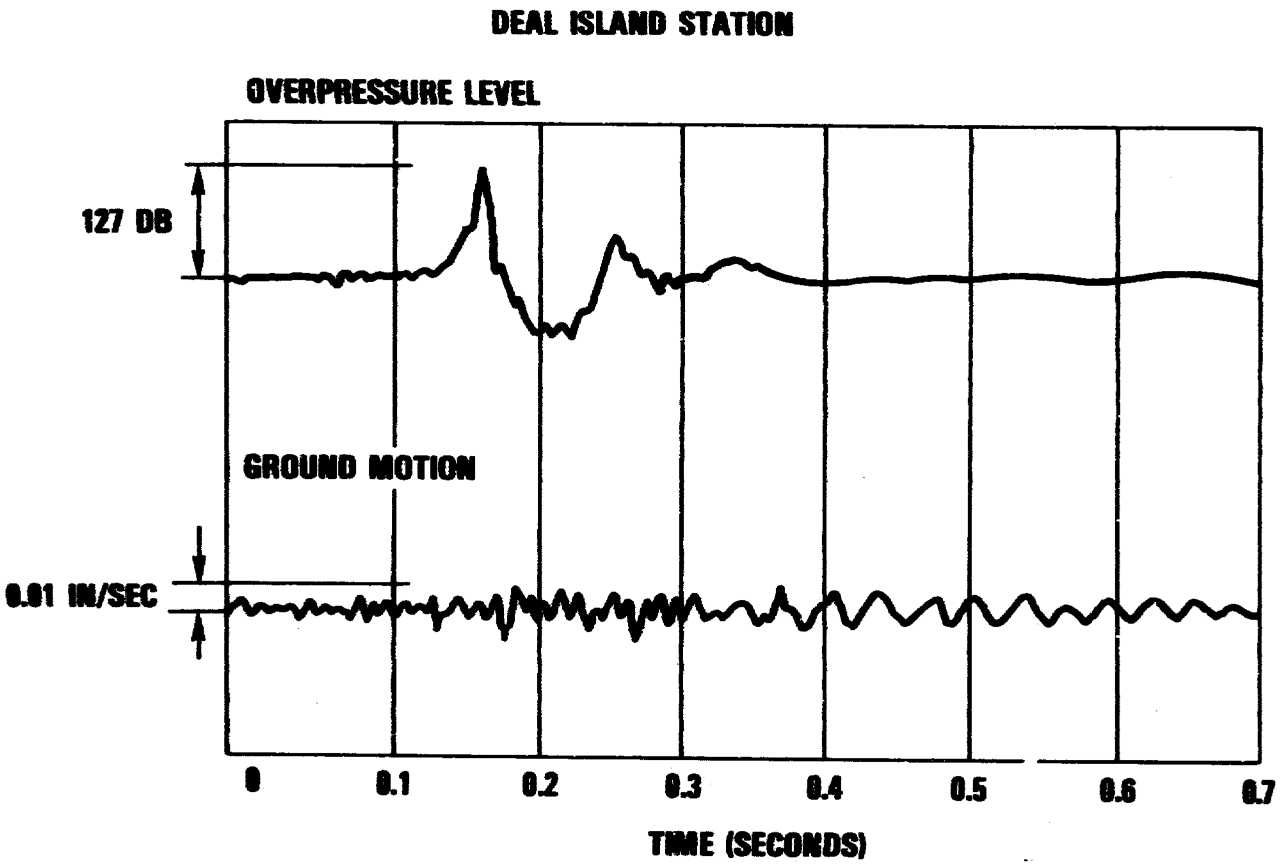

FIGURE 3. TYPICAL ANALOG RECORDS OF MK 82 BOMB EVENTS

TOP POINT STATION

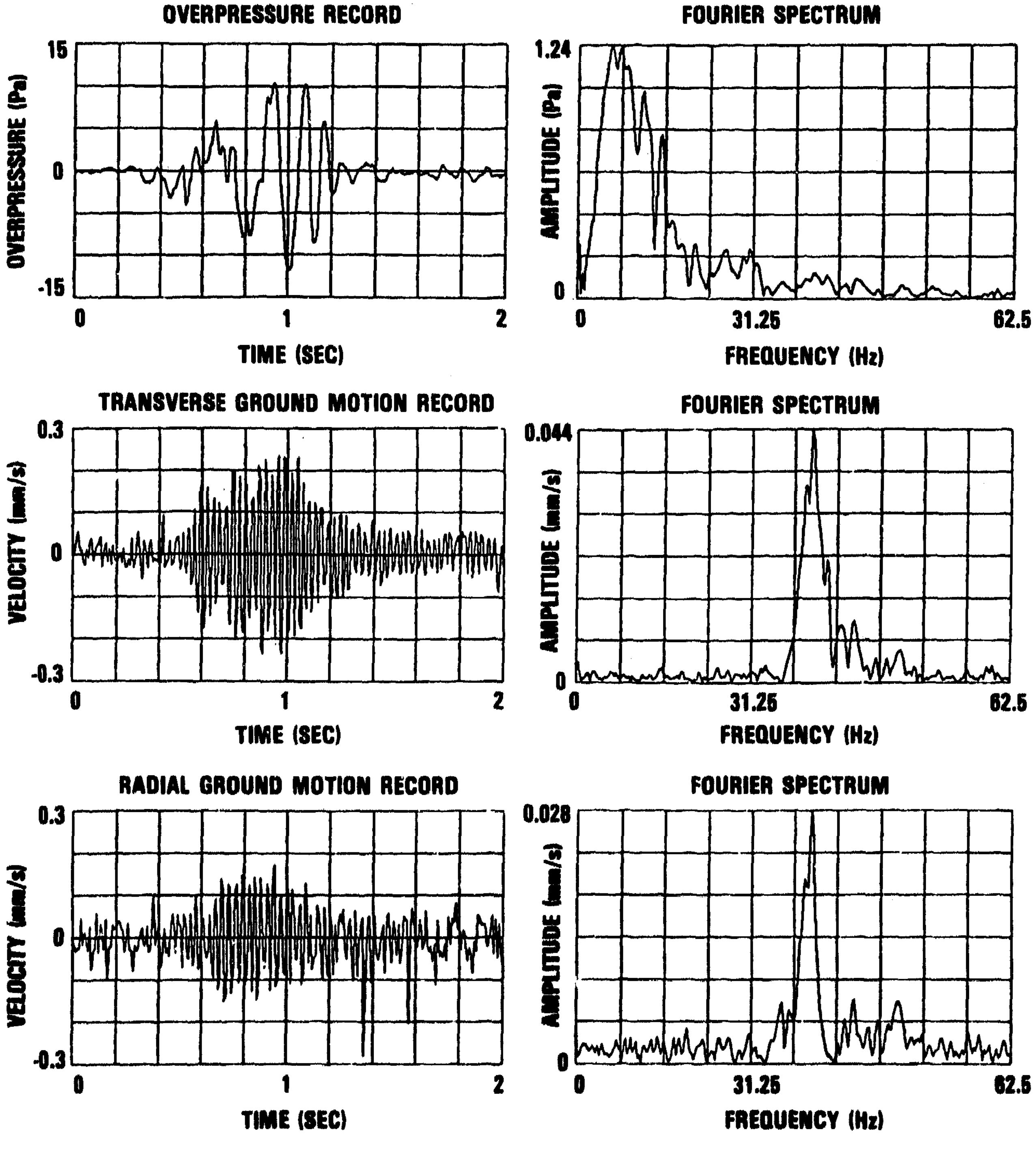

FIGURE 4. TYPICAL DIGITIZED RECORDS OF MK 82 BOMB EVENTS

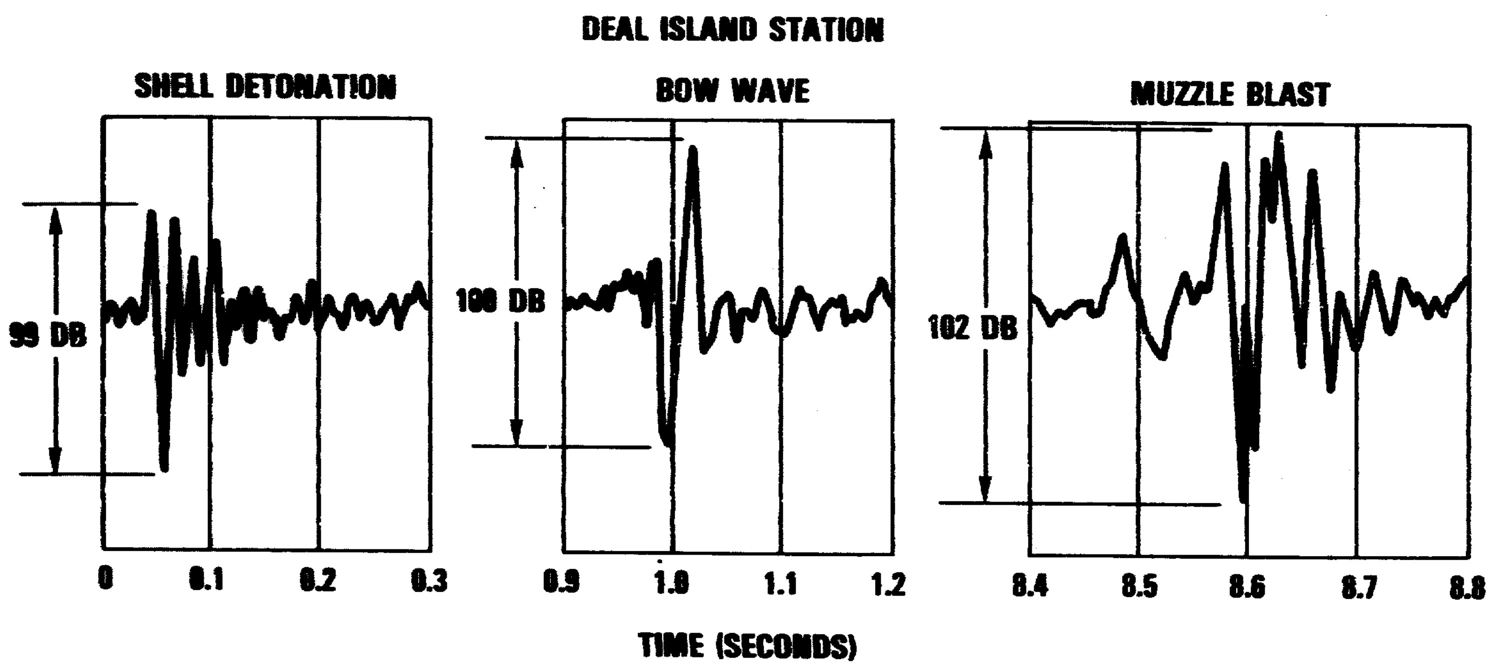

FIGURE 5. TYPICAL ANALOG RECORD OF 5"/54 NAVAL GUNFIRE

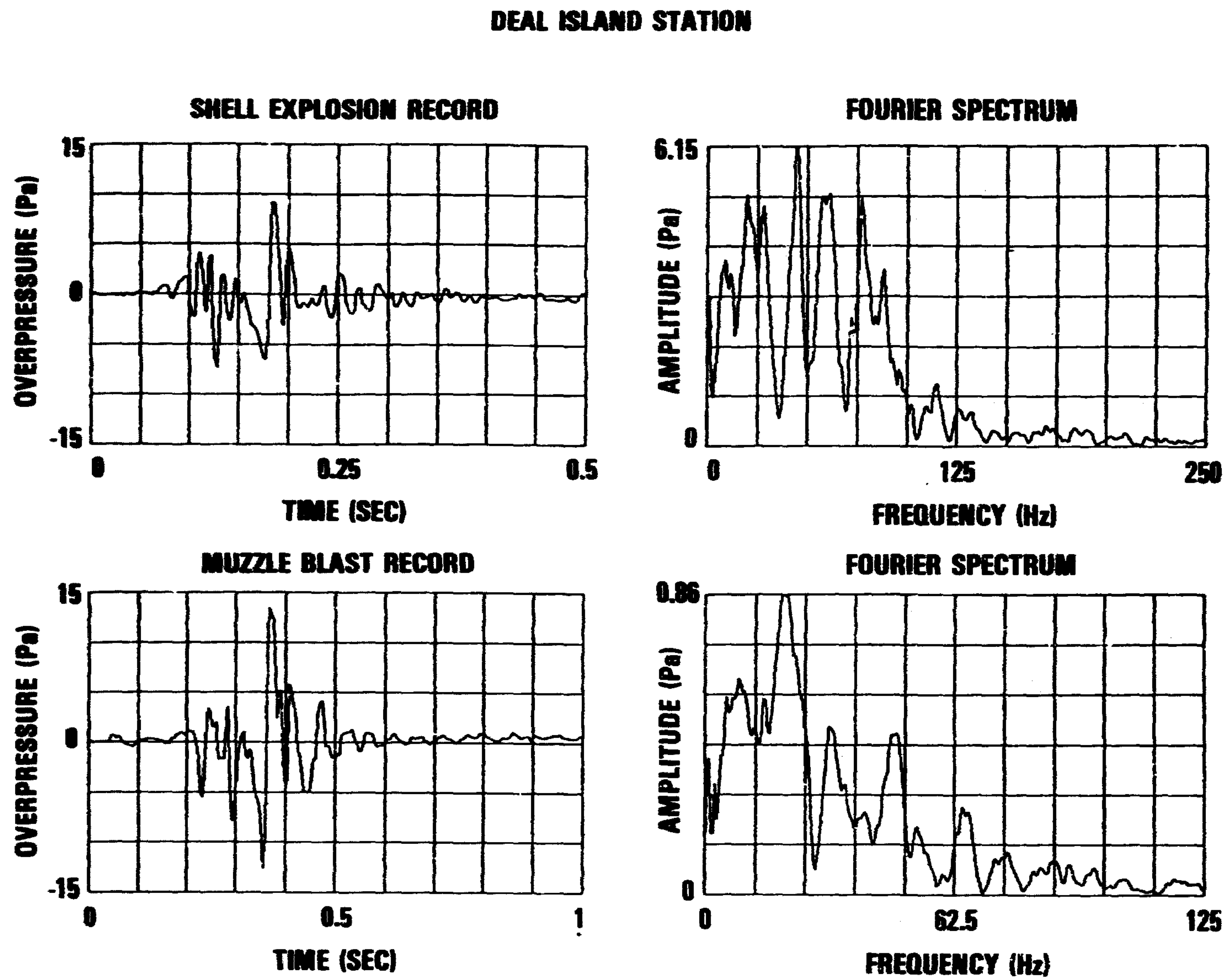

FIGURE 6. TYPICAL DIGITIZED RECORDS OF 5"/38 NAVAL GUNFIRE

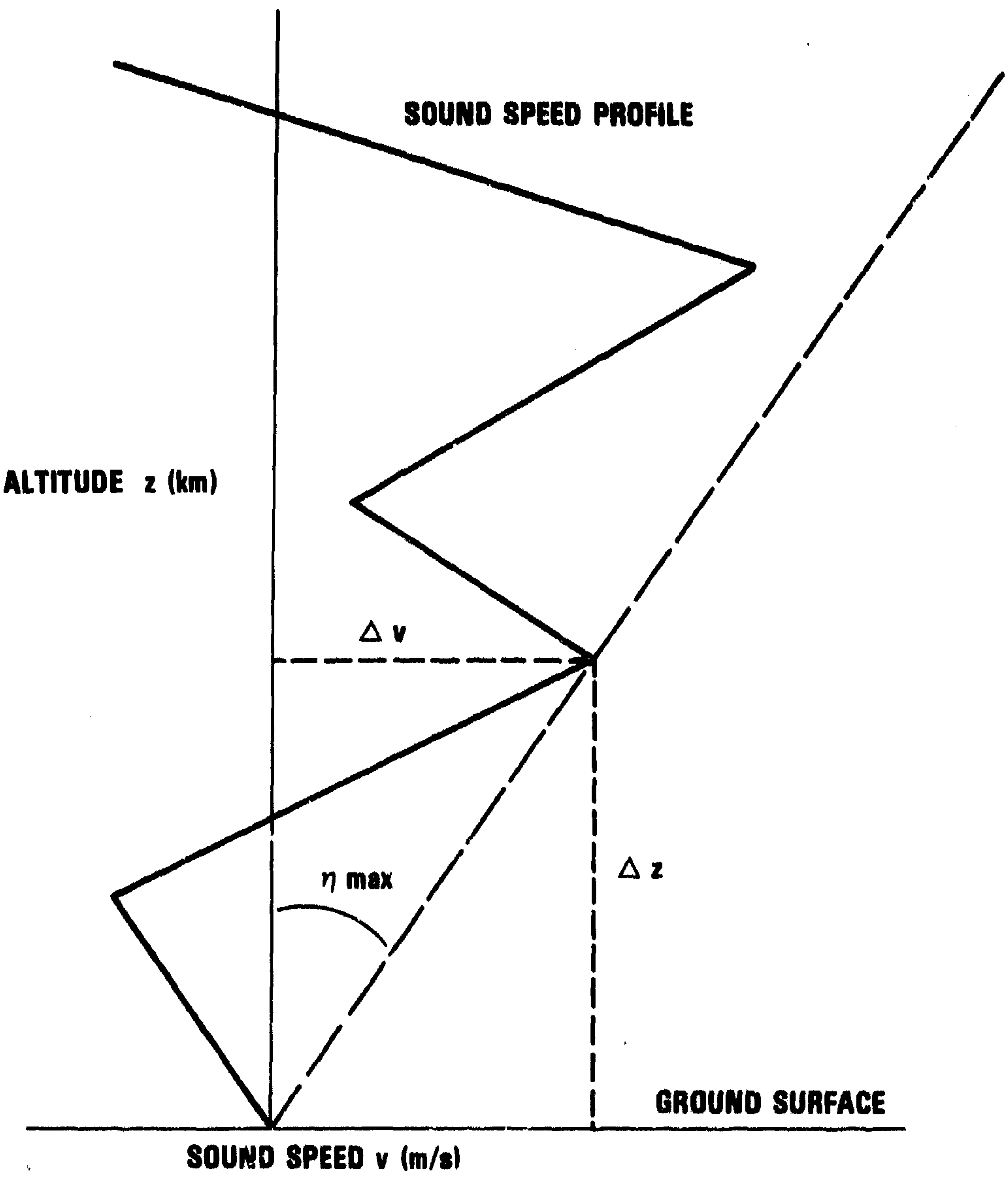

FIGURE 7. DIAGRAM DEFINING TERMS IN EQUATION 2

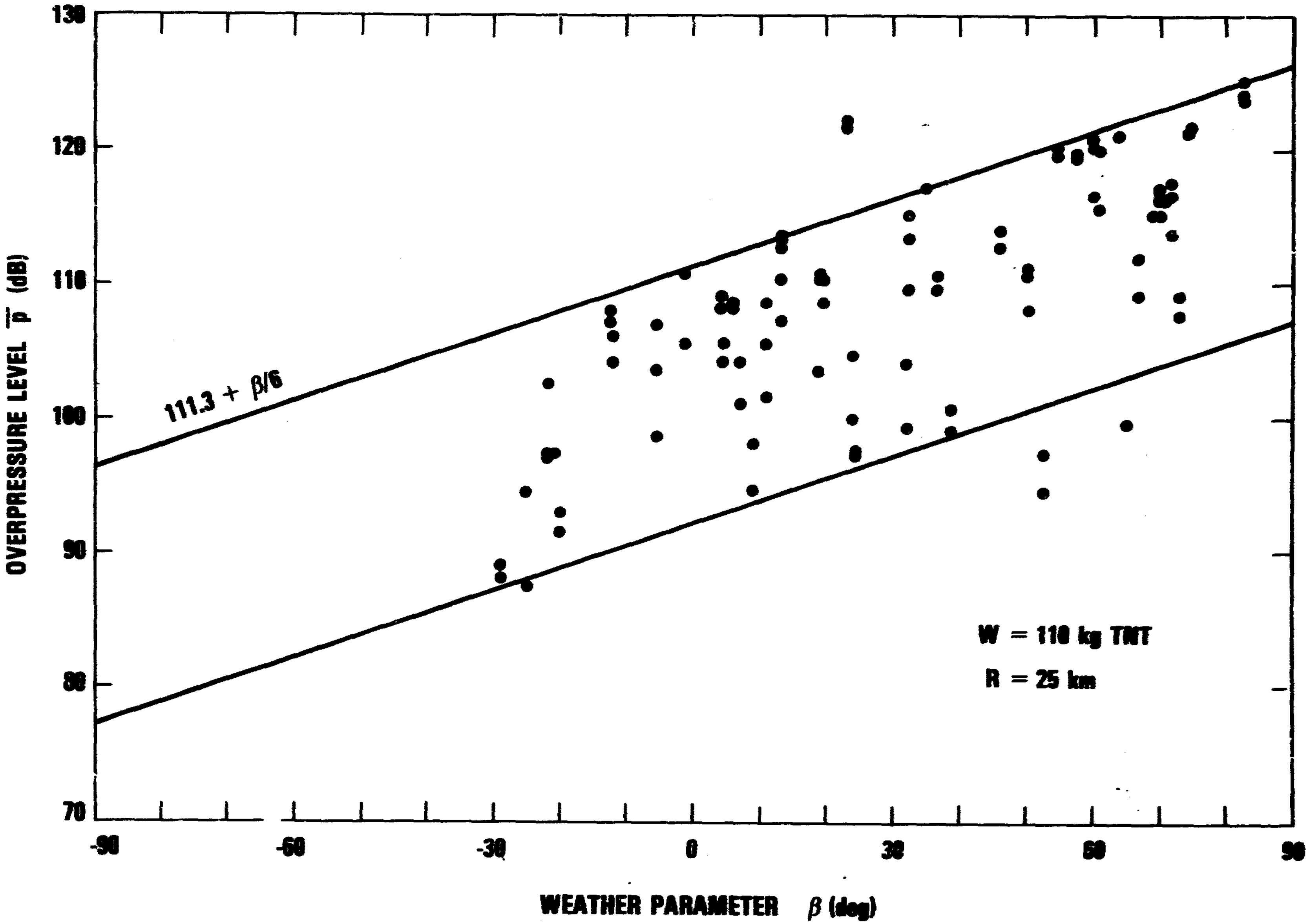

FIGURE 8. MK 82 BOMB DATA FROM TOP POINT AND CRISFIELD

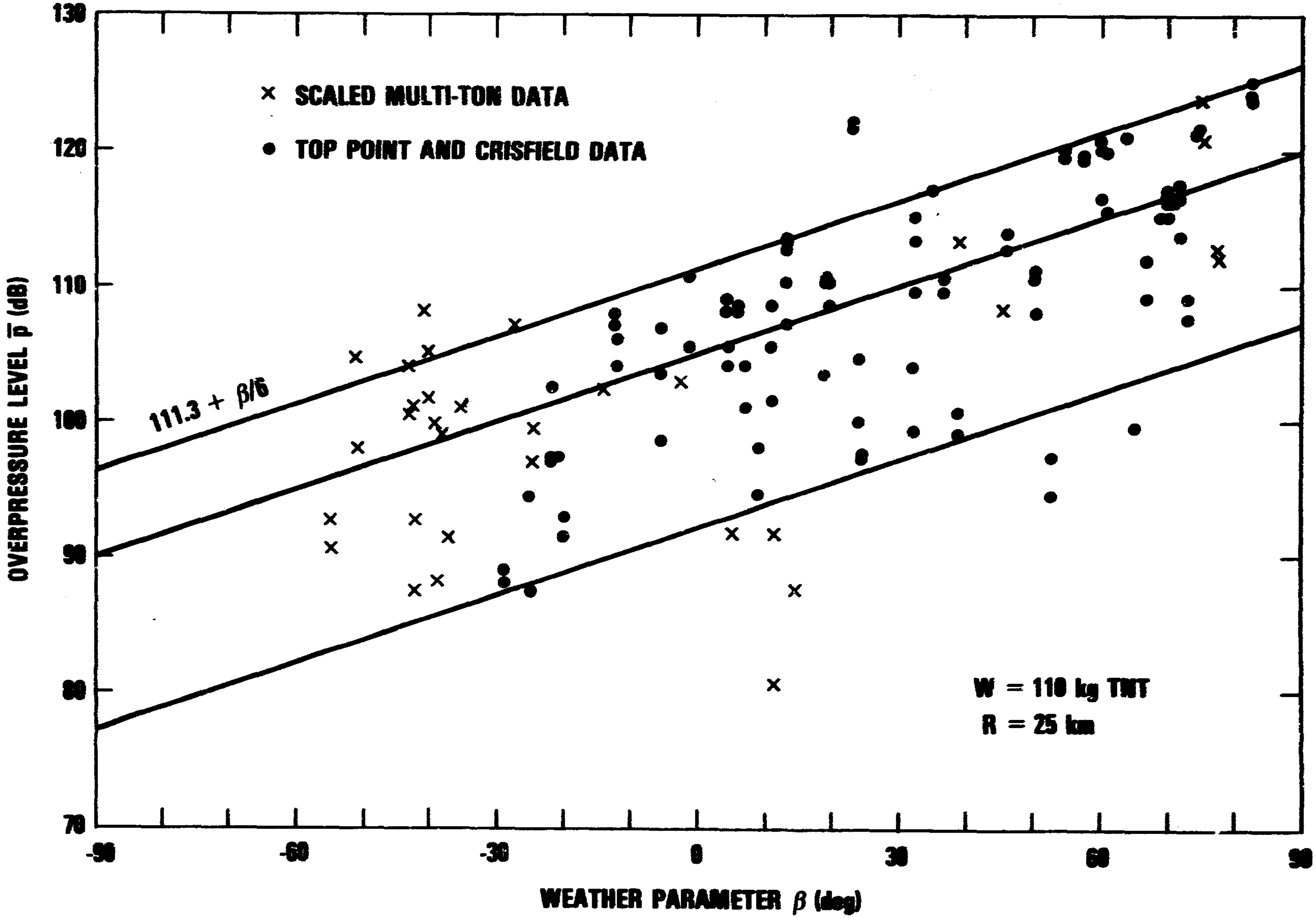

FIGURE 9. SCALED MULTI-TON DATA WITH TOP POINT AND CRISFIELD MK 82 BOMB DATA

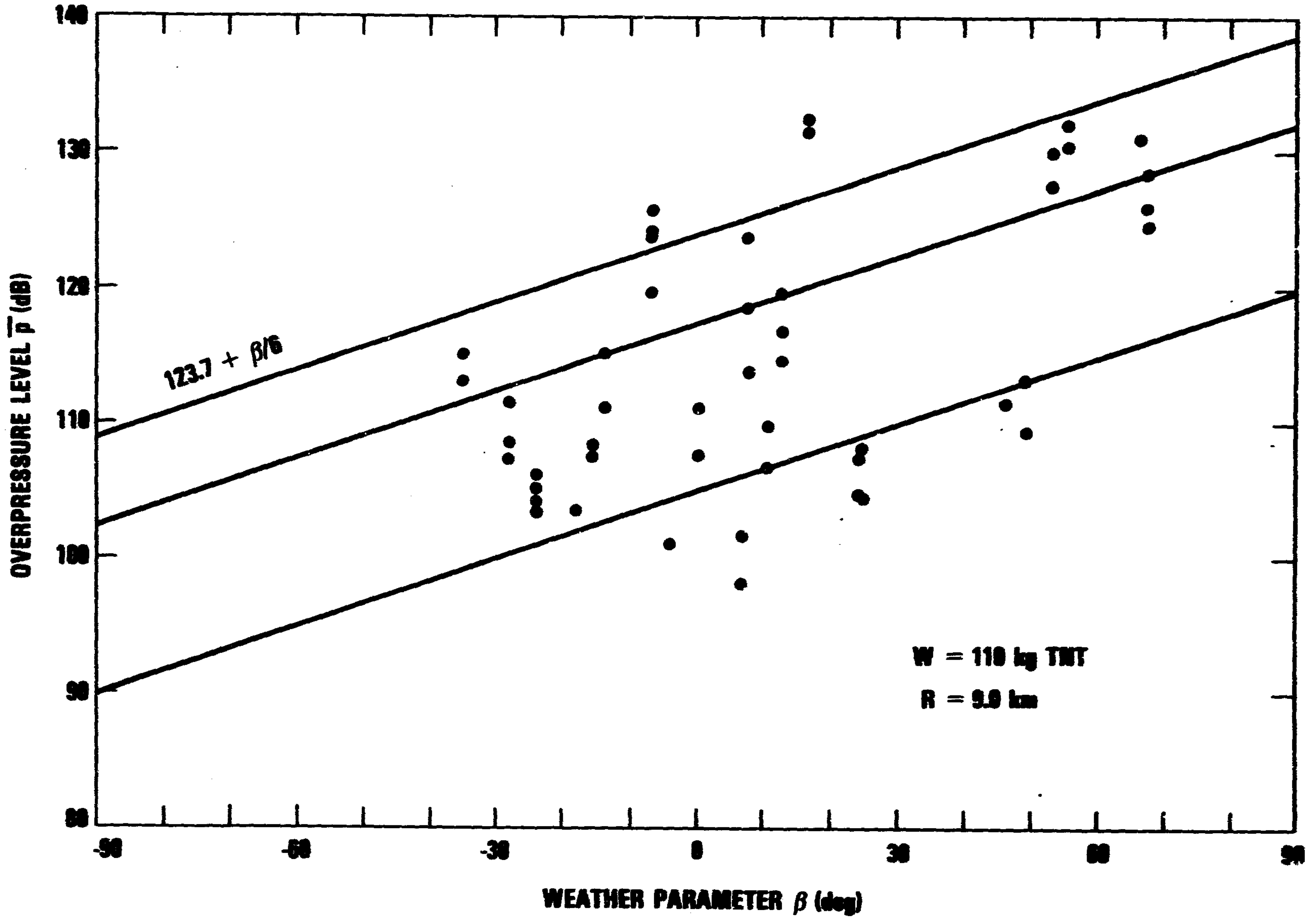

FIGURE 10. MK 82 BOMB DATA FROM DEAL ISLAND

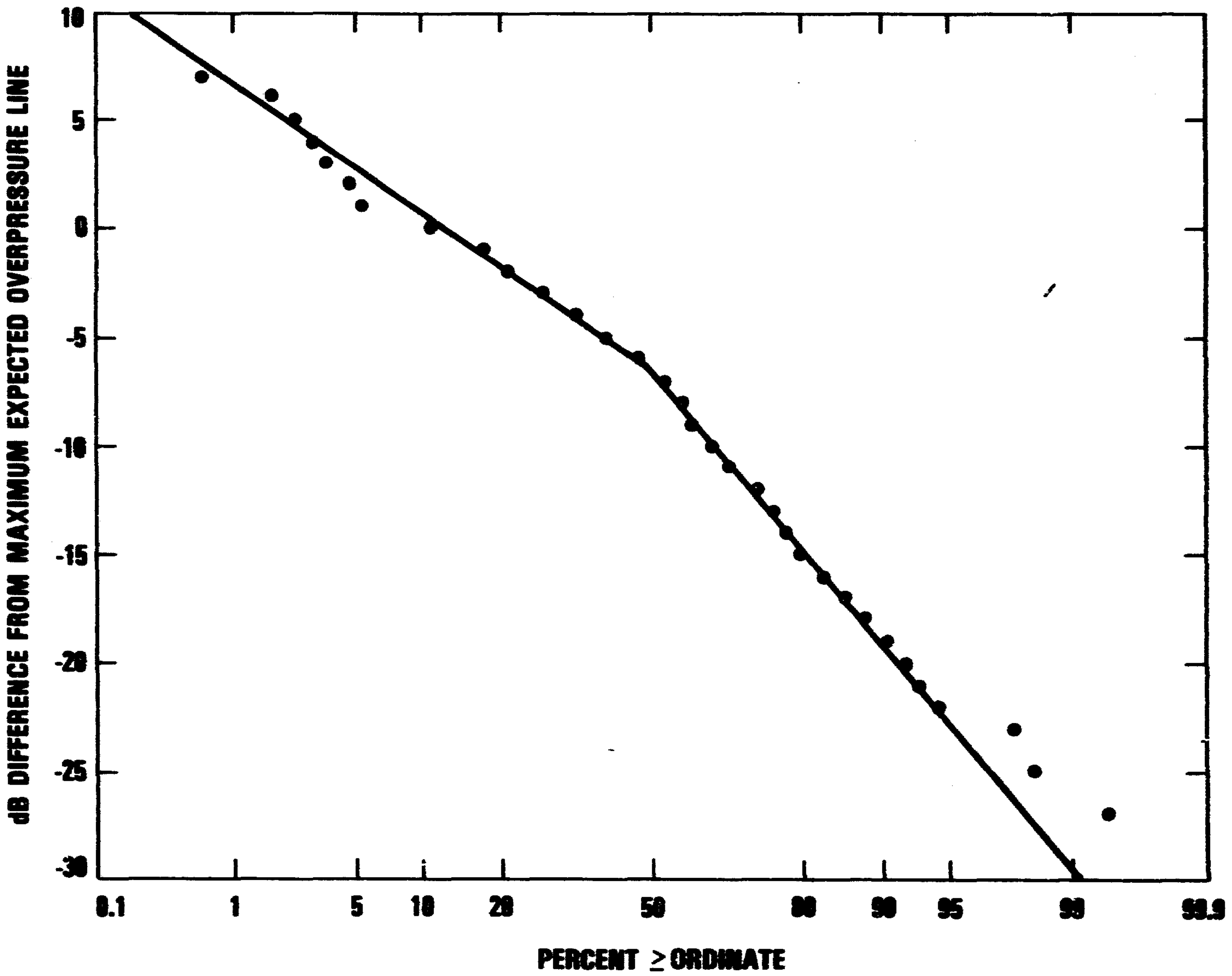

FIGURE 11. DISTRIBUTION OF MK 82 BOMB AND MULTI-TON DATA

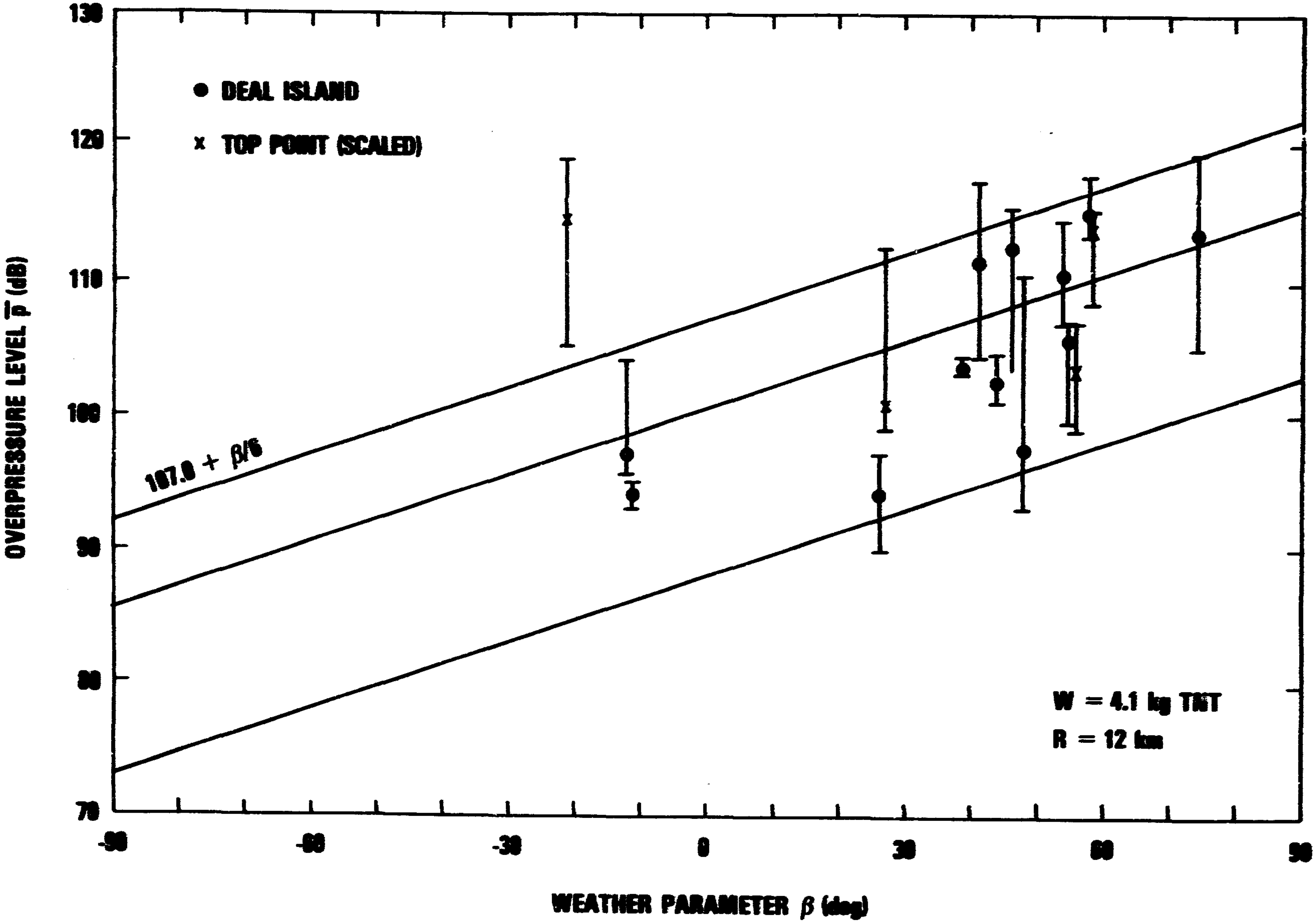

FIGURE 12. 5" SHELL EXPLOSION DATA FROM DEAL ISLAND AND TOP POINT

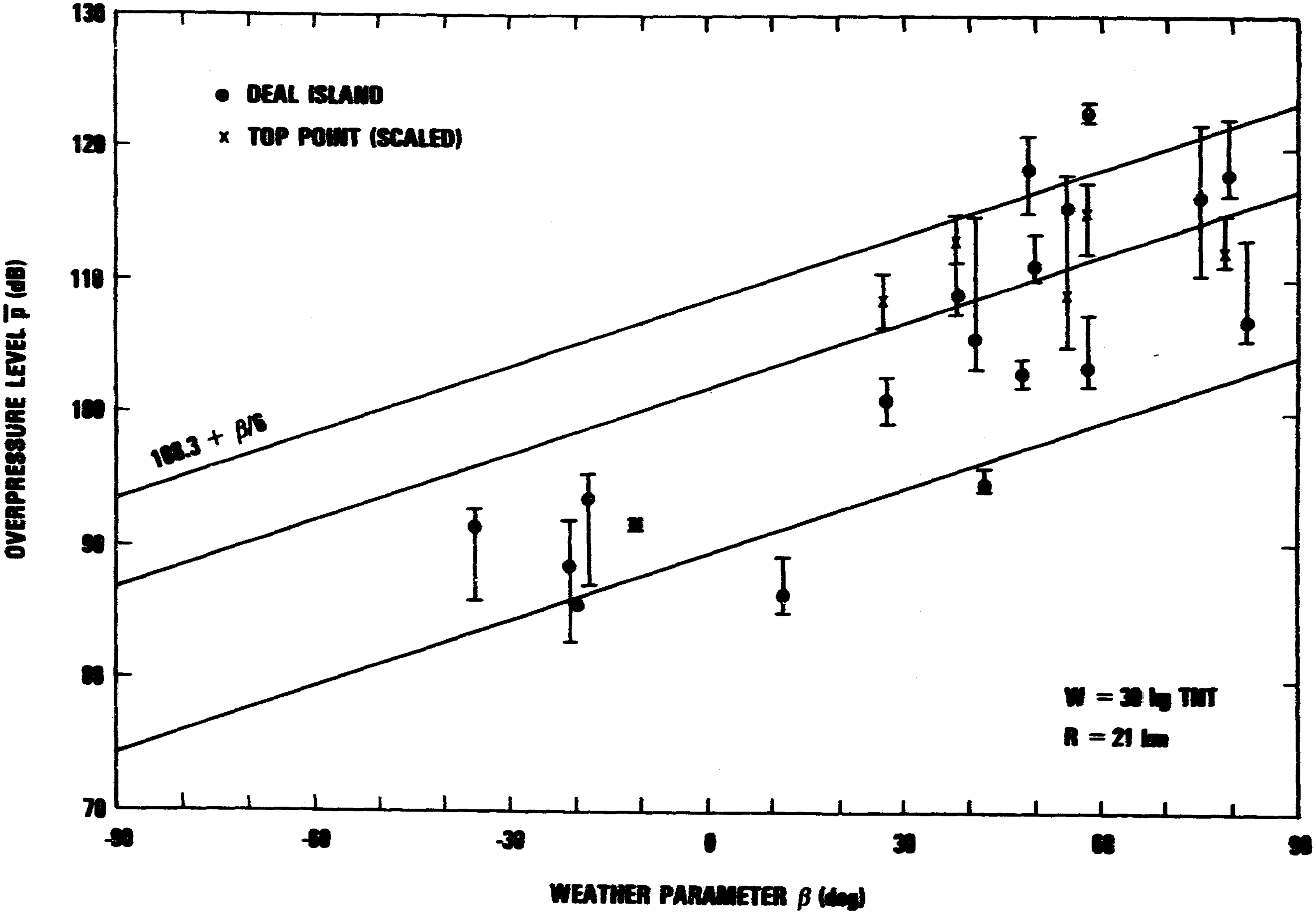

FIGURE 13. MUZZLE BLAST DATA FROM DEAL ISLAND AND TOP POINT

APPENDIX A

AN APPROXIMATE METHOD FOR DETERMINING FOCAL POINT RANGES

This appendix describes an approximation which greatly simplifies the determination of focal points (locations on the ground surface at which sound rays are concentrated by the lens effect of the atmosphere). The standard ray tracing methods[A1, A2, A3] require that a large number of ray paths be calculated in order to ensure that no focal point is missed. With the new approximation, focal points are calculated in a straightforward manner and only one ray path calculation is required for each possible focal point.

The sound speed versus altitude profile must first be constructed using Equation 1 of the text. Figure A1 shows the nomenclature convention used in this appendix: altitude interval "i" extends from z_i to z_{i+1}, with interval "1" beginning on the ground surface. The slope K_i is

$$K_i = \frac{v_{i+1} - v_i}{z_{i+1} - z_i} \qquad \text{(A1)}$$

In ray tracing theory, a sound ray is considered to be travelling in a particular direction as it leaves the source. Snell's law is assumed to hold over the entire ray path:

$$\frac{\cos \theta}{v} = \text{constant} = \frac{1}{v_{max}} \qquad \text{(A2)}$$

where θ is the angle between the ray path direction and the horizontal, v is the sound speed at the current altitude of the sound ray, and v_{max} is the sound speed at the altitude where the ray turns over ($\cos \theta = 1$) and is determined by the initial angle and sound speed. Because of Equation A2, the path of a sound ray uniquely specified by the sound speed profile once the initial angle θ is selected.

The range R of a ray path is the distance from the source to that point at which the ray touches the ground. In this appendix the source and the touchdown point are assumed to be at the same altitude. It can be shown[A2, A3] that the range for a ray passing through N complete altitude intervals and turning over in interval N + 1 $\left(K_{N+1} > 0\right)$ is:

[A1] Cox, E. F., "Far Transmission of Air Blast Waves", Phys. Fluids 1, 95-101, Mar-Apr 1958

[A2] Perkins, B., Jr., Lorrain, P. H., and Townsend, W. H., "Forecasting the Focus of Air Blasts due to Meteorological Conditions in the Lower Atmosphere", BRL Report No. 1118, Oct 1960

[A3] Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual", NSWC/DL TR-3786, Mar 1978

$$R_{N+1} = \sum_{i=1}^{N} \frac{2\, v_i}{K_i \cos\theta_i} (\sin\theta_i - \sin\theta_{i+1}) + \frac{2\, v_{N+1}}{K_{N+1}} \tan\theta_{N+1} \tag{A3}$$

Using Equation A2 and noting that

$$\sin\theta_i = \sqrt{1 - \cos^2\theta_i} = \sqrt{1 - v_i^2 / v_{max}^2} \quad ;$$

Equation A3 can be rewritten:

$$R_{N+1} = \sum_{i=1}^{N} \frac{2\, v_{max}}{K_i} \left(\sqrt{1 - v_i^2/v_{max}^2} - \sqrt{1 - v_{i+1}^2/v_{max}^2} \right) + \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \tag{A4}$$

The simplifying approximation is made at this point. (In order to avoid showing a large amount of algebra, only the directions for the operations to be performed will be given.) Since v_i is always less than v_{max} in the first N intervals, the two terms in the Parentheses in Equation A4 can be expanded in Taylor series. Collect terms according to descending powers of v_{max}. A factor of $(v_i^2 - v_{i+1}^2)/v_{max}^2$ can now be taken out of each term. The remainder for each term is a summation of the products of various powers of v_i and v_{i+1}. Now make the approximation

$$v_i \sim v_{i+1} \sim \bar{v} \tag{A5}$$

where $\bar{v}$ is the average sound speed in the first N altitude intervals:

$$\bar{v} = \sum_{i=1}^{N} (z_{i+1} - z_i)\,(v_i + v_{i+1})/2(z_{N+1} - z_1) \tag{A6}$$

When this approximation is made, the remainder terms are seen to be the expansion of $-1/2\sqrt{1 - \bar{v}^2 / v_{max}^2}$ so that the parentheses term in Equation A4 is simply $(v_{i+1}^2 - v_i^2)/2\, v_{max} \sqrt{v_{max}^2 - \bar{v}^2}$.

Equation A4 then becomes

$$R_{N+1} = \sum_{i=1}^{N} \frac{(v_{i+1}^2 - v_i^2)}{K_i \sqrt{v_{max}^2 - \bar{v}^2}} + \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \tag{A7}$$

Using Equations A1 and A6, Equation A7 eventually becomes

$$R_{N+1} = \frac{2\,(z_{N+1} - z_1)\,\bar{v}}{\sqrt{v_{max}^2 - \bar{v}^2}} + \frac{2}{K_{N+1}} \sqrt{v_{max}^2 - v_{N+1}^2} \tag{A8}$$

There can be situations where the range R first decreases and then increases as the initial angle of departure θ gradually increases. A focal point exists where the range reverses direction, that is, at a value of R such that

$$\frac{dR}{d\theta} = \frac{dR}{d\cos\theta} = \frac{dR}{d\,v_{max}} = 0 \qquad \text{(A9)}$$

where use has been made of Equation A2. When Equation A9 is applied to Equation A8, the condition for a focal point becomes:

$$0 = \frac{(z_{N+1} - z_1)\,\bar{v}}{(v_{max}^2 - \bar{v}^2)^{3/2}} - \frac{1}{K_{N+1}\sqrt{v_{max}^2 - v_{N+1}^2}} \qquad \text{(A10)}$$

where v_{max} is the unknown quantity to be solved for. The focal point is determined when the v_{max} specified by Equation A10 is substituted into Equation A8.

Equation A10 can be transformed into a cubic equation for v_{max} by squaring the two terms on opposite sides of the equal sign. This means that only half of the three cubic solutions will be physically meaningful. It can be shown that if

$$x = \frac{(v_{max}^2 - \bar{v}^2)}{K_{N+1}\left(z_{N+1} - z_1\right)\bar{v}} \quad \text{and} \quad \cos\phi = \frac{\sqrt{27}}{2}\,\frac{(\bar{v}^2 - v_{N+1}^2)}{K_{N+1}\left(z_{N+1} - z_1\right)\bar{v}} \qquad \text{(A11)}$$

then the cubic equation is:

$$0 = x^3 - x - \frac{2}{\sqrt{27}}\cos\phi \qquad \text{(A12)}$$

This equation is in the desired form for standard cubic solution techniques.[A4] The physical solutions are:

$$x = \frac{1}{\sqrt{3}}\left(\cos\phi + \sqrt{\cos^2\phi - 1}\right)^{1/3} + \frac{1}{\sqrt{3}}\left(\cos\phi - \sqrt{\cos^2\phi - 1}\right)^{1/3}, \quad \text{for } \cos\phi > 1 \qquad \text{(A13)}$$

$$x = \frac{2}{\sqrt{3}}\cos(\phi/3), \quad \text{for } |\cos\phi| \le 1 \qquad \text{(A14)}$$

There is no real solution for $\cos\phi < -1$. This is a non-physical restriction since focal points can exist for $\cos\phi < -1$. This problem will be addressed again below. When a cubic solution exists, the focal range is given by:

[A4] Beyer, W. H., editor, CRC Handbook of Mathematical Sciences, 5th edition, CRC Press, Inc., 1978

$$R_{Focal} = 4\sqrt{\frac{(z_{N+1} - z_1)\ \bar{v}}{K_{N+1}}} \left(\frac{1 + x^2}{2\sqrt{x}}\right) \tag{A15}$$

This value for the focal range was obtained with the assumption that there was no upper bound on the altitude interval N + 1. Therefore, the existence of the calculated focal range must be checked by performing a standard ray path calculation using the initial angle of departure Θ specified by $v_{max} = v_{N+2}$. If the range for this ray is greater than or equal to the calculated focal range, then this focal point does physically exist; otherwise not. This checking procedure implies that the focal point calculation need be made only for those situations where v_{N+2} is greater than all sound speeds at lower altitudes. This means that any sound speed profile needs to be evaluated only once from the ground up, with the average velocity $\bar{v}$ being continuously updated and a focal range calculation made only when a new maximum velocity is found.

The focal range given by Equation A15 is always less than or equal to the focal range obtained by an exact ray path search. Comparisons for a number of simple profiles showed that the approximate focal ranges were generally within a few percent of the "exact" focal ranges. The relative errors tended to be less for the shorter focal ranges.

It was mentioned earlier that when $\cos\phi < -1$ in Equation A11, there was no real cubic solution even when physical focal points did exist. To obtain solutions in this region, use the following set of equations:

$$W = \frac{(\bar{v}^2 - v_{N+1}^2)}{K_{N+1}\ (z_{N+1} - z_1)\ \bar{v}} = \frac{2}{\sqrt{27}} \cos\phi \tag{A16}$$

$$R_{Focus} = 4\sqrt{\frac{(z_{N+1} - z_1)\ \bar{v}}{K_{N+1}}}\ (1 + W)^{1/4} \tag{A17}$$

This set is related to a derivation in which the average sound speed $\bar{v}$ was defined slightly differently than in Equation A6 so that the equation corresponding to Equation A12 was quadratic instead of cubic. The quadratic formulation is somewhat less accurate than the cubic formulation, especially for large focal ranges. Figure A2 compares these two formulations. It is recommended that the cubic focal point calculation be used for $\cos\phi > 0$, and the quadratic calculation for $\cos\phi \leq 0$.

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A3. Pollet, D. A., "Sound Intensity Prediction System for the Island of Kahoolawe; Program Maintenance Manual", NSWC/DL TR-3786, Mar 1978

A4. Beyer, W. H., editor, <u>CRC Handbook of Mathematical Sciences</u>, 5th edition, CRC Press, Inc., 1978

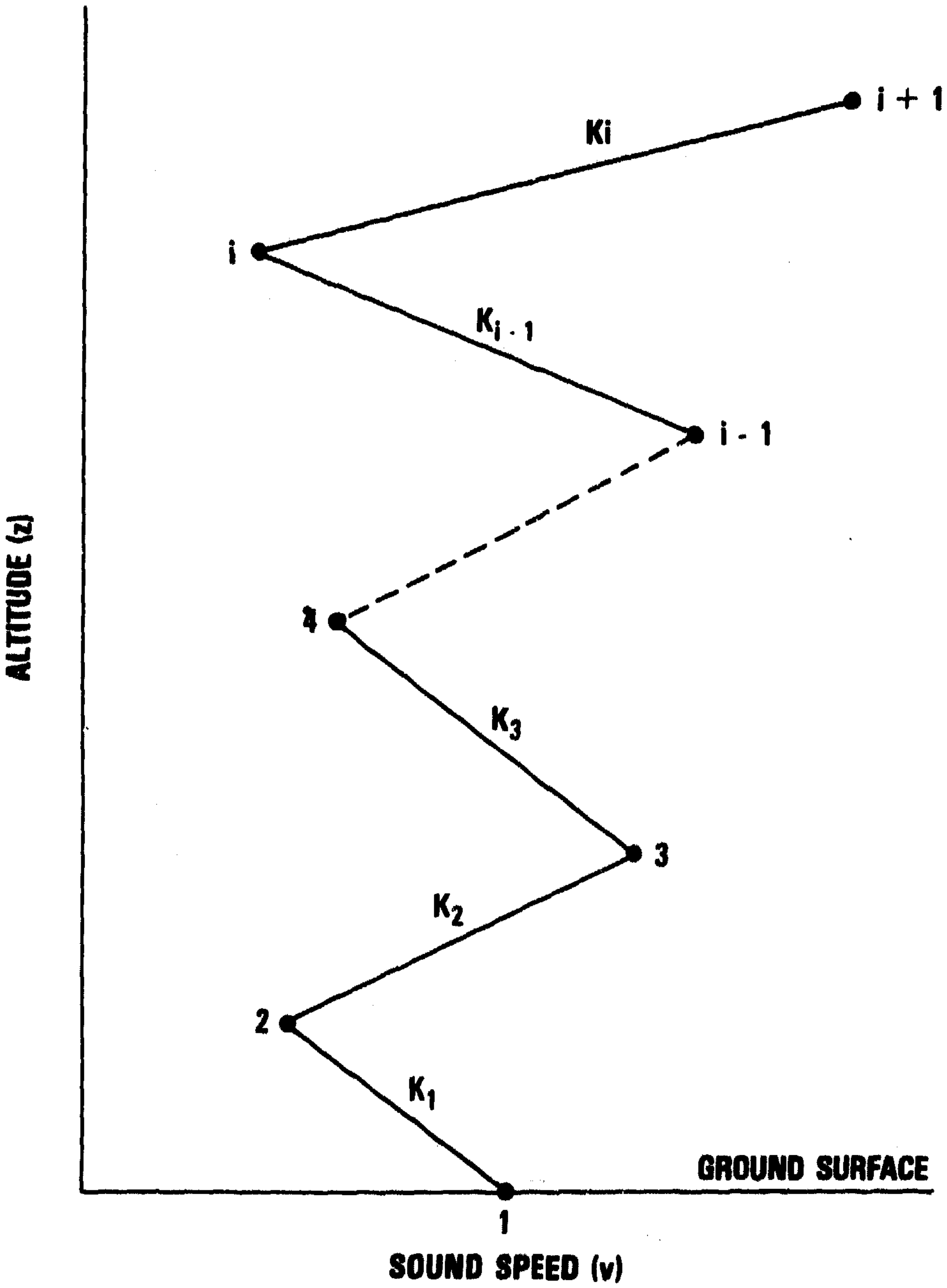

FIGURE A1. SOUND SPEED PROFILE INDEXING CONVENTION

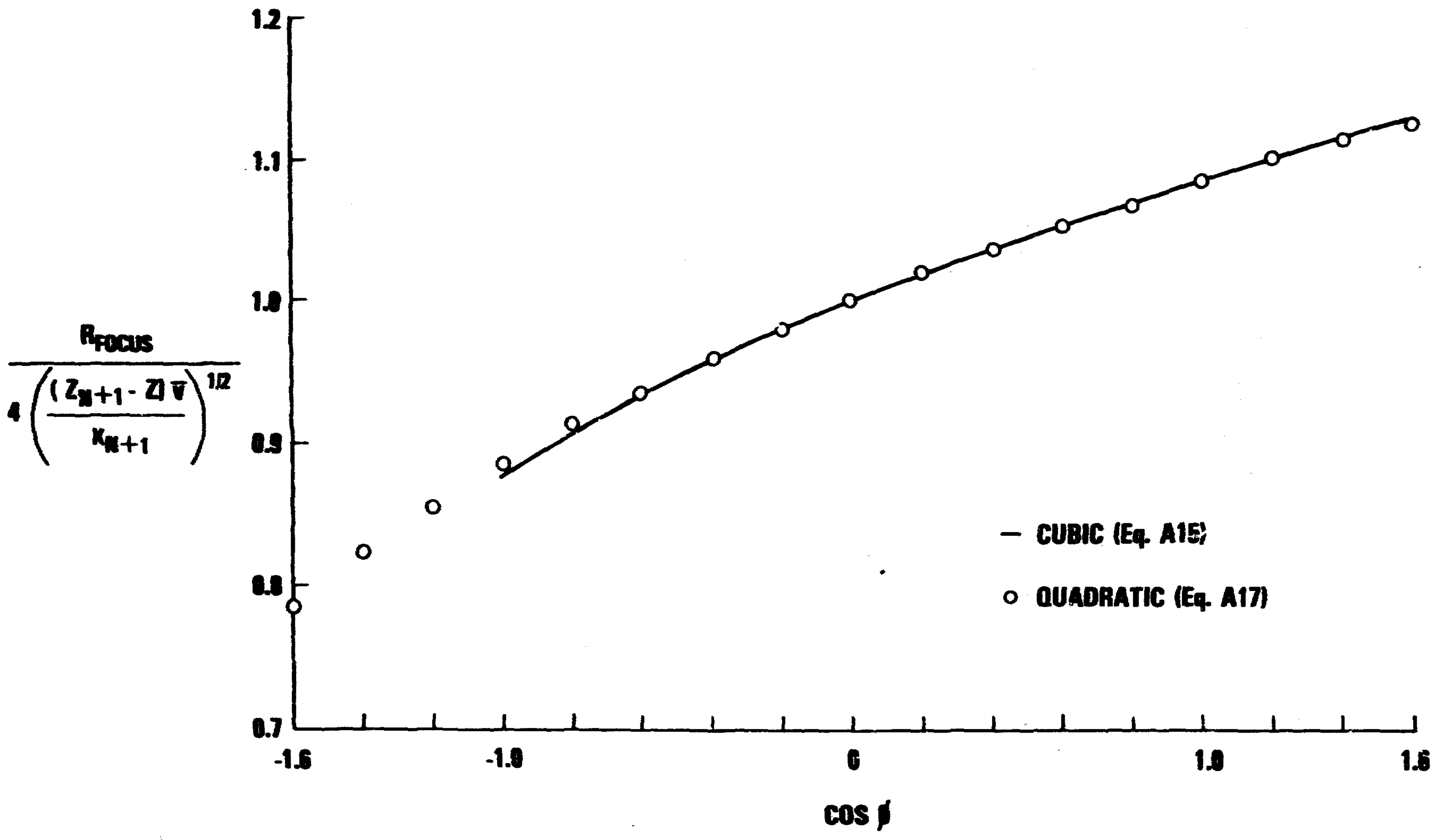

FIGURE A2. COMPARISON OF CUBIC AND QUADRATIC FOCAL POINT PREDICTION FORMULAS

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SAND 80-1880C

PROJECT PROPA-GATOR--INTERMEDIATE RANGE EXPLOSION AIRBLAST PROPAGATION MEASUREMENTS*

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ABSTRACT

Several hundred explosions of flaked TNT, ranging in charge weight from 2.3 kg to 1145 kg were fired at the NASA Kennedy Space Center, Florida, in March and June, 1979. Comprehensive meteorological measurements were made by rawinsonde balloons and on a nearby 150 m tower, including winds, turbulence, temperatures, and humidity. A cruciform array of airblast gages was operated, with gages at 200 m, 500 m, 1 km, 2 km, and 5 km ranges from the explosions. For some events as many as six microbarographs were operated at distances to 25 km. Airblast results have been correlated against refractive atmospheric conditions, establishing a functional relationship between overpressure decay with distance and the sound velocity gradient with height.

*This work was jointly supported by DOD, DOE, and NASA.

INTRODUCTION

Project PROPA-GATOR tests were designed to refine predictions of atmospheric refraction effects on propagation of explosion airblast waves.[1] The first phase was conducted on the NASA Kennedy Space Center (KSC), Florida (see Fig. 1), in collaboration with the USAF Eastern Space and Missile Center (ESMC), in March and June of 1979, over relatively flat terrain and near a 150 m meteorological tower[2]. The goal was to determine the correlation between enhancement or attenuation of airblast overpressures as a function of the boundary layer sound velocity versus height gradient or inversion with ray propagations as sketched in Fig. 2. Classic ray trace models yield the discontinuous amplification result shown in Fig. 3.

Previous measurements had not established a good correlation between propagated amplitudes and the strength of the vertical gradient of atmospheric sound velocity. Gradient strength is defined, for dimension scales of this project, as the maximum increase (inversion) or decrease (gradient) of directed sound velocity, from the surface value, observed in the atmospheric boundary layer. Two rules-of-thumb had been developed over the years of atmospheric nuclear testing to treat these propagations. First, inversions could double or triple propagated overpressures and amplitudes at intermediate to long ranges [3]. Second, for strong gradient propagation, in the overpressure-distance decay proportionality, $\Delta p \sim R^{-a}$, an exponent of $a=2$ was frequently found,[4] whereas the standard

spherical explosion [5] follows a=1.1 at moderate to low overpressures, and infinitesimal amplitude acoustic decay should follow a=1.0.

It is planned to perform a similar test series over rough terrain at the USAF Western Space and Missile Center (WSMC), Vandenberg AFB, California, in the Spring of 1981, to determine the shadowing effects of mountains and the focusing effects of the usual California coastal temperature inversion and westerly wind.

This report will review the ESMC tests, results, and tentative conclusions that have been reached to date.

AIRbLAST MEASUREMENTS

Recordings of airblast pressure versus time signatures were made at five distances (200 m, 500 m, 1 km, 2 km, and 5 km) from three explosion yields (2.3 kg, 45 kg, and 1145 kg) at various yield-scaled (proportional to the cube root of yield) heights-of-burst (HOB). Pressure gages were placed in a cruciform array with lines directed approximately north, east, south, and west, as shown in Figure 1. Winds were expected to cause differing propagations along the four gage lines for each shot.

Pressure sensors were Statham 2A3, Dynesco DPT-85, and Pace P7D variable-reluctance transducers, with set ranges of 200 Pa to 17 kPa, depending on location. Each station was equipped with two or three sensors of different set ranges to

bracket the expected range of signal amplitudes from the various explosion yields and weather conditions. Sensor signals were transmitted by S-Band (2204.5 - 2288.5 MHz) and P-Band (216.5 - 219.5 MHz) radio telemetry (TM) to a central recording trailer located 900 m from the shot area. All sensors were mounted 1 m above ground level, with entry ports facing down to give side-on ground-reflected pressures. It had previously been established by comparison tests that ground level flush-mounted ports were not required for the signal pressure and frequency ranges being measured.

Analog recordings were made on 14-track magnetic tape by Ampex 2230 recorders operated at 30 ips (0.76 m/s). An IRIG-B time signal and a shot-time zero indicator were entered on each tape.

EXPLOSION SOURCES

From four to seven shots, of various yields and HOBs, were fired at about ten second intervals to form a shot series ("hour"). Three or four series were fired at two to three hour intervals on each of seven shot days in the March (winter) tests, and six days in the June (summer) tests. Flaked TNT from USAF outdated surplus stocks was used for all explosions.

WEATHER MEASUREMENTS

Teletyped reports of tower weather data were recorded for several levels on Tower T-313 every five minutes during operations. Temperature was measured at 6 levels, dewpoint temperature at 4 levels, and wind vector at 7 levels. A rawinsonde

balloon ascension was made for each shot hour to give wind, temperature and humidity data at higher altitudes, at about 300 m intervals.

DATA REDUCTION

The volume of data collected, over 15,000 pressure signatures from winter and summer KSC phases, dictated computer processing. The first stage was to digitize all analog magnetic tape records at 1 ms intervals at the RCA TEL-4 station on KSC. Time windows were then estimated for the arrival time for each signal from shot times, shot and gage positions, and atmospheric sound velocity calculations. Excerpts of all digital records were extracted for each signal window on the Cape Canaveral Air Force Station (CCAFS) computer. Condensed record tapes, containing only the signal windows, have been used for analysis at Sandia.

Editing these records for extraneous noises was slow and tedious. It was found that low signal-to-noise problems with weak signals could be well resolved by smoothing over 2 ms intervals. Occasional spikes of electrical noise required hand-edited removal. About 3% of attempted recordings were lost through gage malfunction, and another 1% from errors in time window selection during the excerpting process.

RESULTS

The standard explosion overpressure-distance curve[5] was scaled for yield and adjusted for HOB to allow calculation of

standard (unrefracted propagation) overpressure and peak-to-peak amplitude for each gaged signal. Measured amplitudes were divided by standard amplitudes to give a "propagation factor" for each signal. An example shown in Figure 4 attempts a three-dimensional depiction of the observed propagation factor (linear scale) versus distance (logarithmic scale) for the four gage-line directions, for one 45 kg shot at 7 m HOB. In this instance, propagation was strongly attenuated in north and west directions, to about 10% of standard amplitude at 5 km range. There was 140% enhancement at 5 km east, and 180% enhancement at 5 km south.

Sound velocity-height structures toward the four gage-line directions for this example are shown in Figure 5. Dashed vertical lines are referenced to sound velocities at the low anemometer height (3.7 m). There is a strong sound velocity-height gradient for north and west directions, which explains the strong attenuation that was observed. Sound velocity inversions for east and south caused enhanced propagations in those directions.

The relationship between atmospheric gradient (or inversion) and propagated amplitude was quantified by an RMS line through the data scatter, as shown in Figure 6. In this example, data collected near the yield-scaled distance of 400 m from a free-air burst of 1 kg HE show increasing (decreasing) amplitudes with increasing sound velocity inversion (gradient) strength, as expected. The unexpected result

was that there appeared to be no strong correlation with the thickness or depth of the propagating layer. Similar scatter diagrams and RMS lines were constructed for 1 kg HE scaled distances of 40 m, 100 m, 200 m, and 1 km. Results have been assembled in transformed coordinates, as shown in Figure 7, to show the different overpressure-distance curves that may be expected (along with statistical scatter indicators) with various gradient and inversion strengths, for conditions of clearly indicated gradients or inversions.

When sound velocity changes little with height (near zero strength inversion or gradient), there is considerable uncertainty about propagation. Small but complex variations in wind and temperature may cause ducting and even focusing for some directions or gages. Figure 8 shows that the greatest scatter was observed when such complex weather conditions were encountered. These results have resisted explanation by either ray tracing or correlation with atmospheric structural details. With only one or two meter per second variations of sound velocity with height, distant propagation may be as strong as with the strongest inversions.

DISCUSSION

There were some inconsistent indications that HOB effects and Mach-stem formations [6] were influenced by local winds or sound velocity structures. A similar inference had been drawn earlier from an NSWC explosion test at Dahlgren NAS, VA.[7]

HOB effects were clouded at ESMC by other factors in the analyses performed so far.

In general, source strengths appeared weaker than expected as observed by the closest gages. A few individual gages were apparently biased by as much as 30% as judged by comparisons made between different gages in a canister. Final readings used empirical corrective adjustments that forced averaged readings from each gage in a canister into agreement and also forced canister averages to fall on a smooth pressure-distance curve.

It appears that the flaked TNT gave smaller airblast than could be expected from cast TNT. A yield correction factor of 0.89 was derived from winter test results from 1145 kg HE shots. Results have been adjusted accordingly, but an even smaller factor may be warranted according to the sparse literature that has been found on this subject.

Finally, the soft sand ground and palmetto brush cover on the snake- and alligator-infested terrain (adjacent to the Cape Canaveral National Seashore Wildlife Refuge) appears to have absorbed an appreciable amount of airblast energy, even close-in during Mach-stem formations. Tests at WSMC over harder ground should elucidate these interrelated yield and reflection factor problems. It should then be possible to re-analyze ESMC data, and re-evaluate HOB influences, to determine whether or not local weather did indeed modify Mach wave formation. Results of that process may well necessitate

a completely revised analysis for weather dependence, if the source strength was indeed different for each gage line because of wind effects. There should not, however, be more than 20% or 30% adjustments, so that present results are still much more precise than previous predictions for intermediate and long range propagation amplitudes.

The inability to explain amplifications that resulted from near standard conditions was similar to the experience of the Blast Unit Research Project (BURP) tests in Nevada in 1960.[8] In BURP, caustic pressures were recorded near 60 km range; they were caused by jet stream winds near 6 km to 10 km altitudes; results did not show a strong, reliable correlation between ray path patterns and recorded airblast amplitudes. It was hoped by some that the smaller distances involved in PROPA-GATOR and the more proximate and more detailed weather observations would reduce the unexplained variance. It appeared, however, that the smaller dimension field was significantly affected by smaller scale weather perturbations, so that the scatter factor remained large.

FUTURE TEST PLANS

Current plans are for similar series of explosion tests at WSMC, beginning in March, 1981. Observed propagations over rough terrain from two firing sites will be compared to predictions for flat terrain propagations under similar sound velocity structures. This should show whether or not mountain barriers indeed cast significant acoustic shadows. There are arguments both ways, for inversion as well as gradient conditions.

In addition, extra instrumentation will be fielded in a further attempt to document caustics from atmospheric airblast focusing. Both the boundary layer temperature inversion and prevailing on-shore winds, typical of coastal southern California, favor complex propagation conditions toward several communities inland from WSMC. Ray path calculations have shown a climatological concentration of caustics about 25 km east from a shot point. Two dense radial gage lines will be operated in that area to collect amplitude statistics that will be used in a further attempt to correlate acoustic characteristics with atmospheric structural details.

CONCLUSIONS

Airblast propagation measurements were made at Kennedy Space Center, Florida, with nearby tower weather data. These have allowed development of a set of weather-dependent overpressure-distance curves with statistical error factors for flat terrain that extend to a yield-scalable distance of 1 km from 1 kg HE free air burst. These curves vary with the amount of increase or decrease in directed sound velocity with height, in well-defined inversion or gradient conditions. This quantification is a significant refinement from previous prediction methodology. Earlier systems simply showed possible ranges for propagations under either typical gradient or typical inversion conditions.

Nevertheless, in borderline or complex cases of sound velocity versus height structure, there is considerable uncertainty about whether propagation will be strongly enhanced or attenuated.

Further refined analyses may be possible from this extensive data collection, once a) the source strength has been better established for flaked TNT, b) the ground reflection factor for palmetto brush and soft sand has been determined, and c) the local wind influence on Mach-stem HOB effects has been resolved.

Further explosion tests are planned for 1981 at Vandenberg AFB, to a) help resolve aforementioned problems with a hard-ground firing site, b) measure the shadowing effects of mountainous terrain, and c) make extensive observations of airblast amplitudes near areas where atmospheric acoustic focusing is expected.

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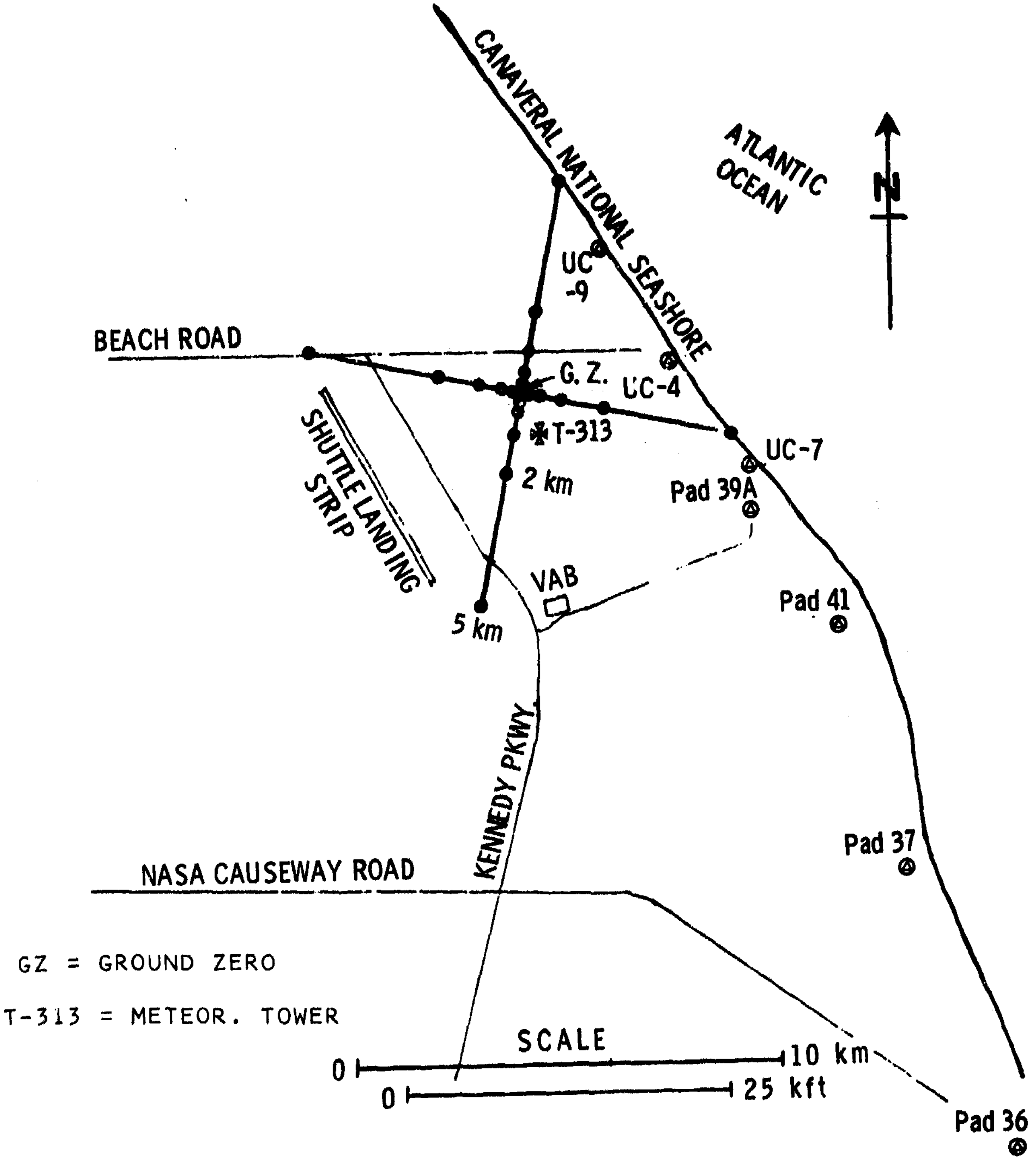
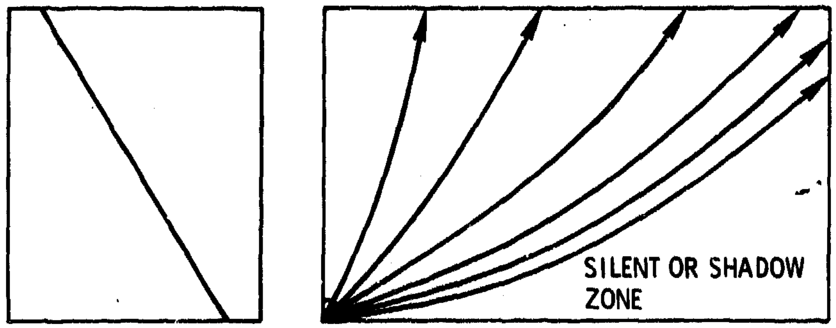
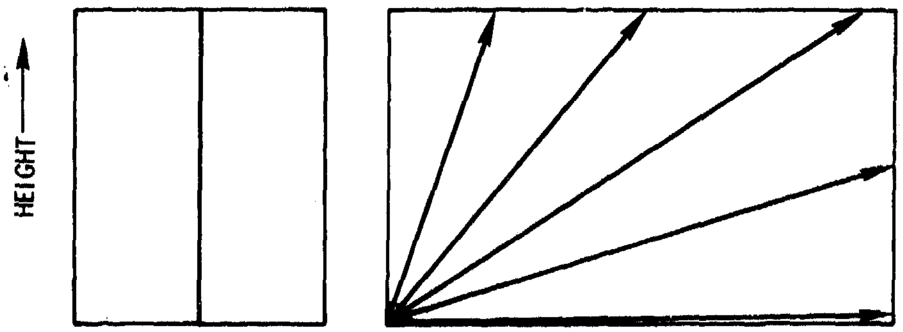


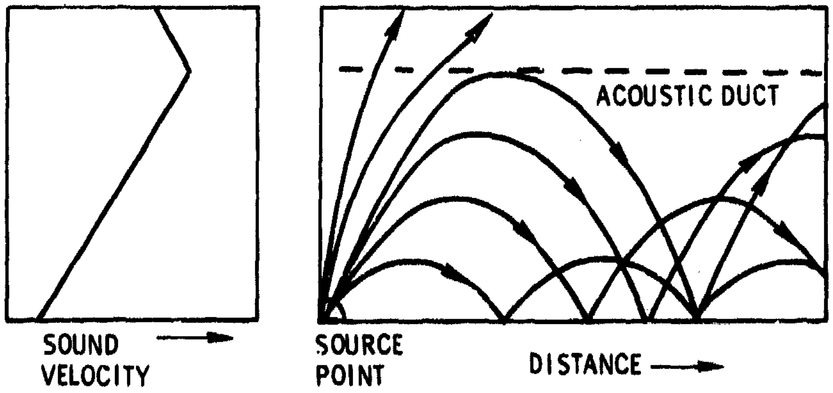
FIGURE 1 MAP OF ETR BLAST PROPAGATION EXPERIMENT AND AIRBLAST GAGE LINES.



a. GRADIENT



b. STANDARD



c. INVERSION

FIGURE 2 ATMOSPHERIC REFRACTION OF ACOUSTIC OR AIRBLAST RAYS.

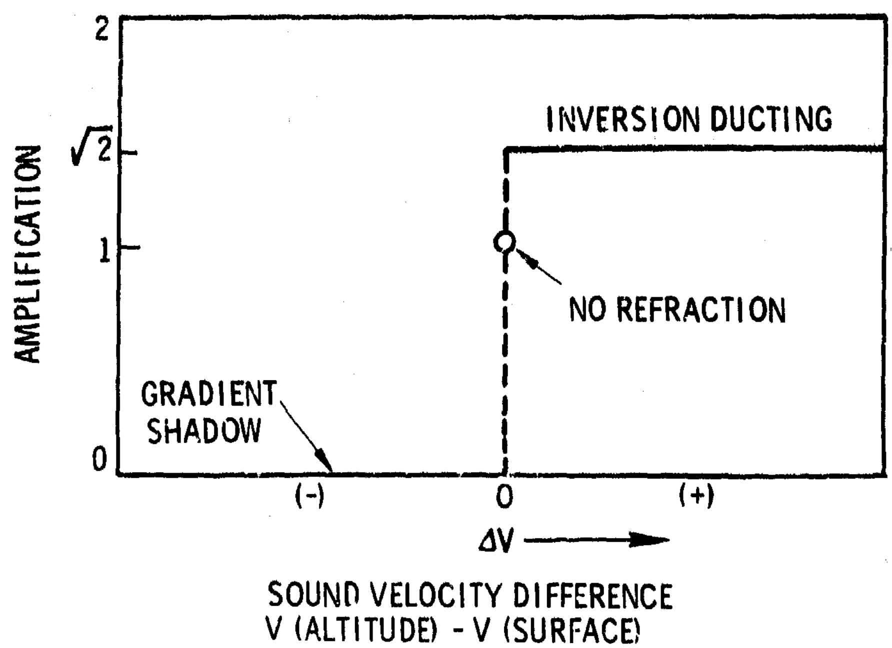


FIGURE 3 AIRBLAST OVERPRESSURE MAGNIFICATION FOR BOUNDARY LAYER PROPAGATION CONDITIONS, ACOUSTIC RAY SOLUTIONS.

PROJECT PROPA-GATOR

EXPLOSION AIRBLAST AMPLIFICATION FACTORS

45 kg TNT @ 7.0 m HOB March 7, 1979

0800 EST

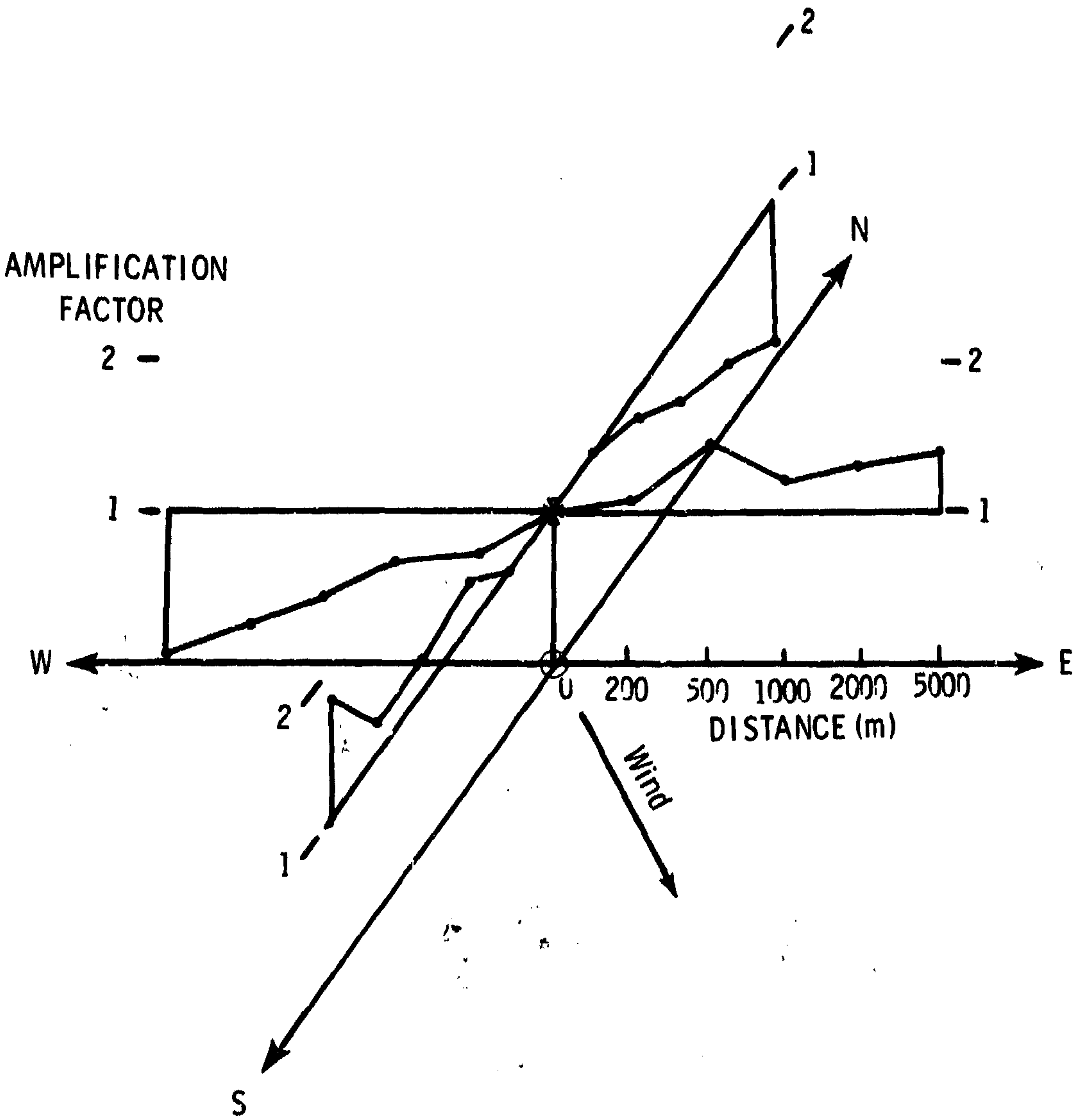
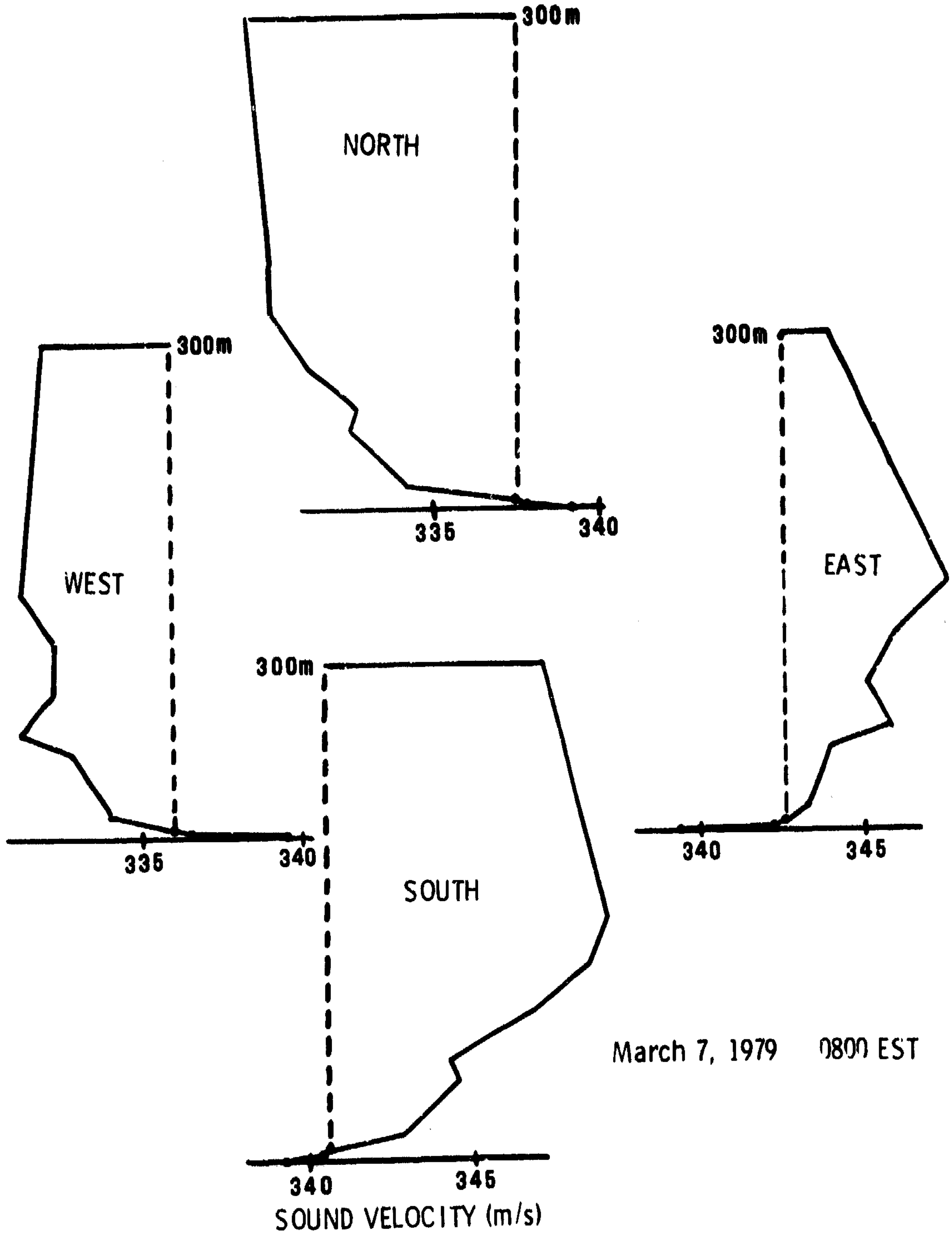
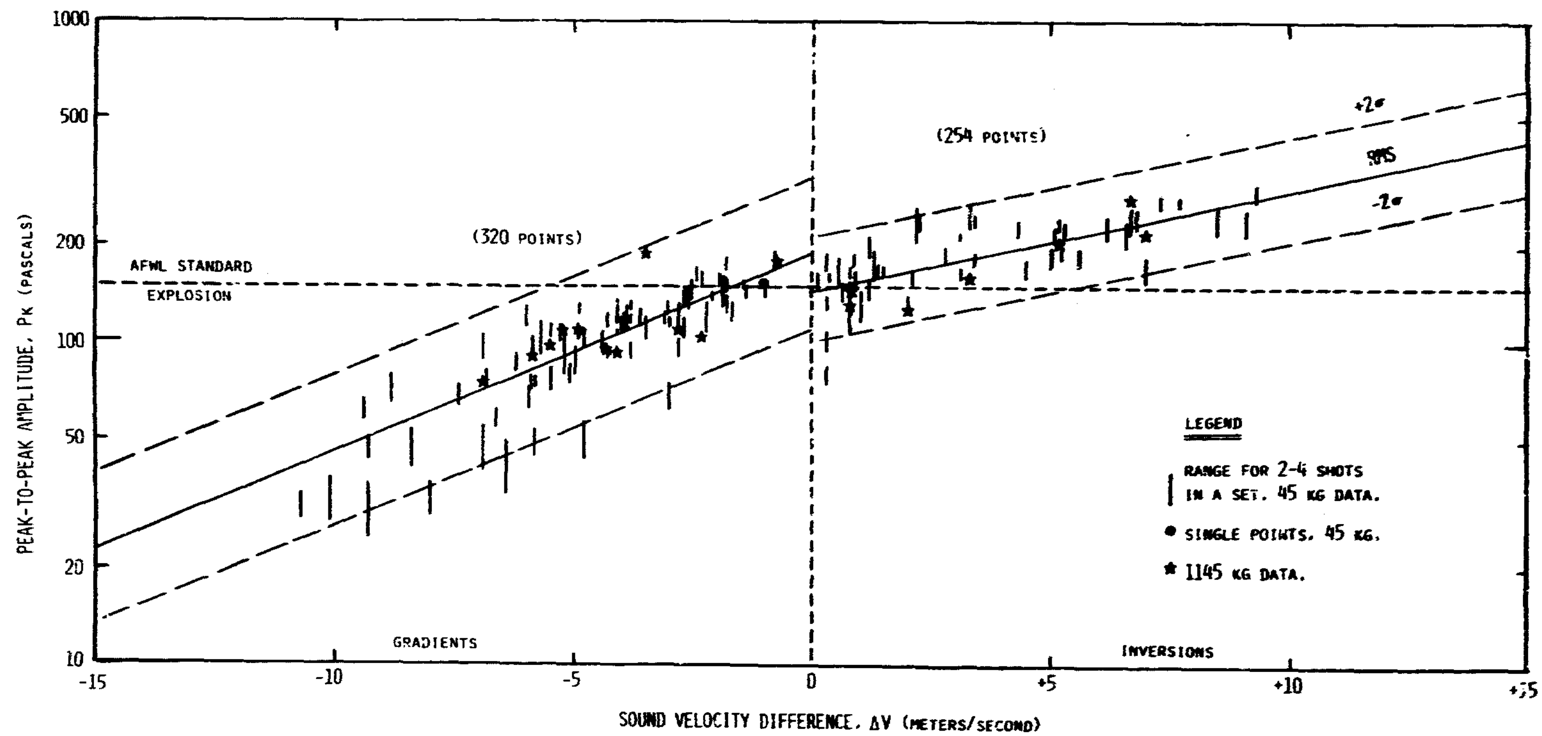


FIGURE 4



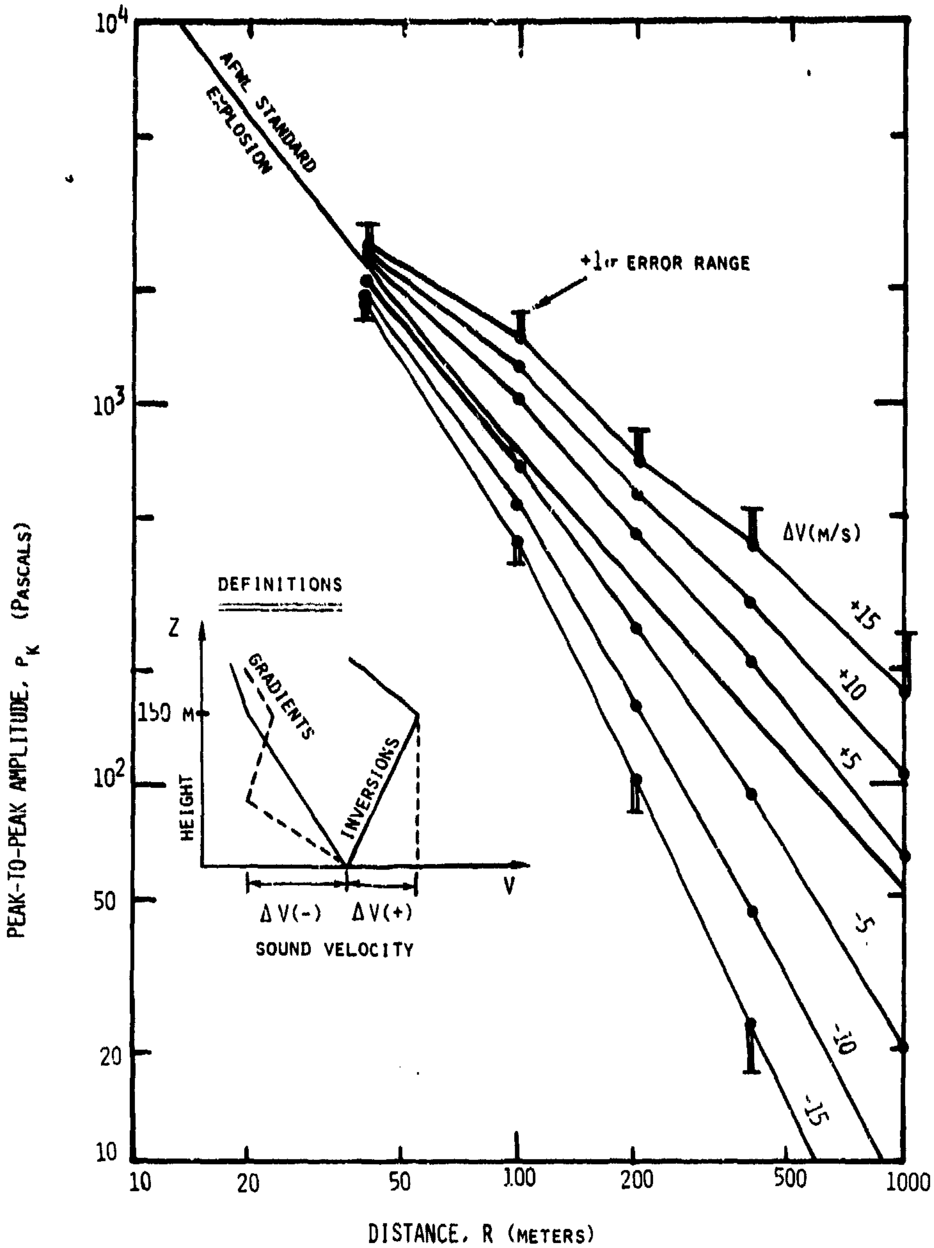
PROJECT PROPA-GATOR
SOUND VELOCITY - HEIGHT STRUCTURES

FIGURE 5



RECORDED PRESSURE AMPLITUDES VERSUS SOUND VELOCITY DIFFERENCES IN THE BOUNDARY LAYER. AT YIELD-SCALED DISTANCE OF 400 m FROM 1 KG TNT.

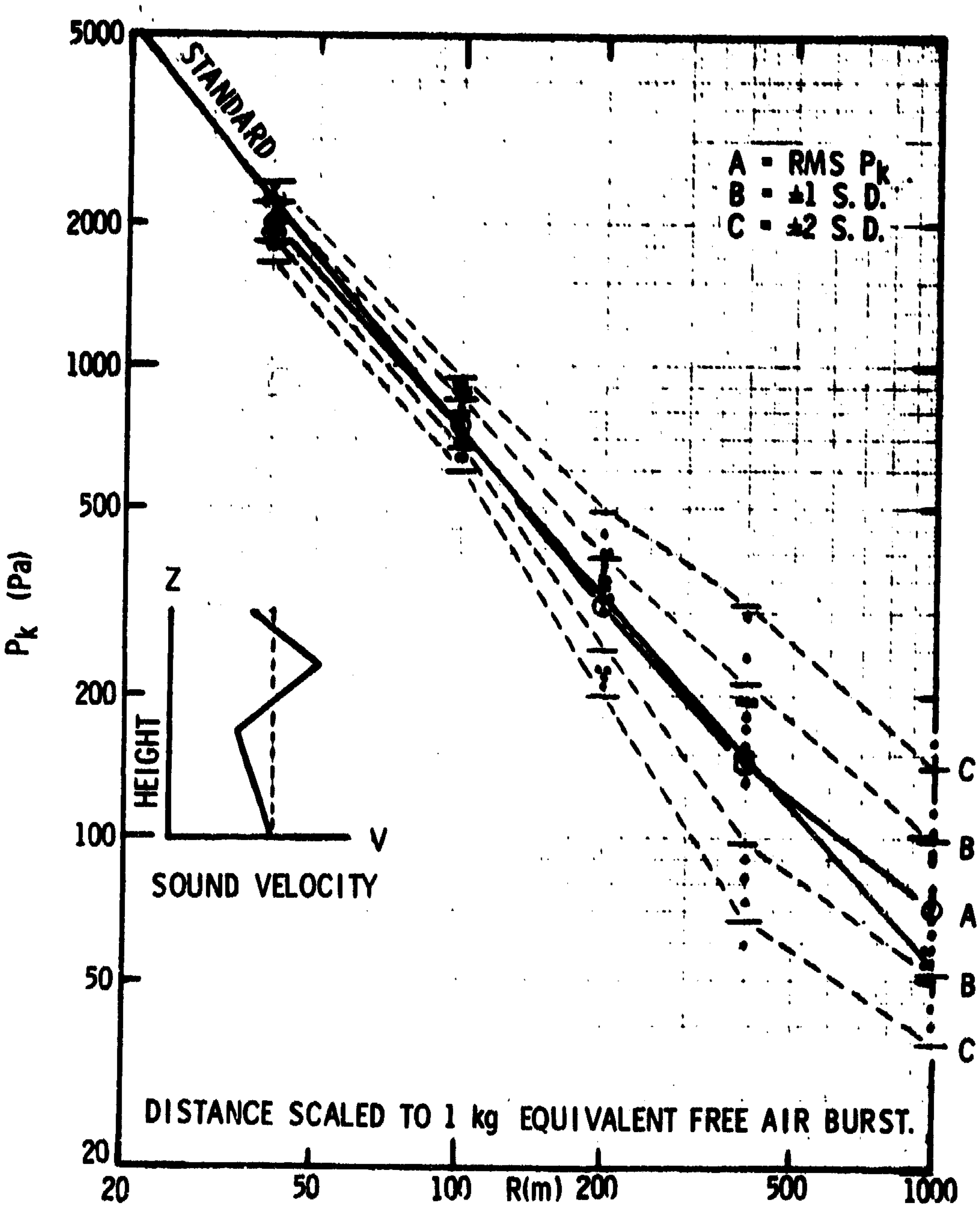
FIGURE 6.



(Scaled to 1 kg TNT Equivalent Free-air Burst)

AIRBLAST AMPLITUDE VS DISTANCE CURVES FOR INVERSION AND GRADIENT ATMOSPHERES.
(Based on 45 kg TNT Explosions)

FIGURE 7.



AIRBLAST AMPLITUDE VS DISTANCE, COMPLEX CONDITIONS.
Based on 19 cases of 45 kg (100 lb) TNT explosions.

FIGURE 8

CHEMICAL AGENT DISPOSAL AND NEW PROTECTIVE EQUIPMENT - A PILOT PLANT APPLICATION

by

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Introduction

Over the last twenty years, chemical munition disposal methods have evolved from burn pits to sea dumping and in recent years to industrial incineration and chemical neutralization. This evolution was brought about by increased concern for man and his environment. Continued development of chemical demilitarization technology allows increased safety through more reliable equipment and more sensitive agent detection and alarm systems.

Chemical munition and agent disposal projects currently in operation or under development are:

- o incapacitating agent BZ disposal,
- o phosgene sale for commercial use,
- o a mobile Drill and Transfer System (DATS),
- o Chemical Agent Identification (ID) Sets disposal, and
- o a prototype Chemical Agent Munitions Disposal System (CAMDS). Disposal of chemical munitions encompasses demilitarization of the chemical agent and its container. As a rule, the container is burned in a furnace and the agent itself is either incinerated or chemically neutralized.

The pilot plant for possible future disposal of chemical munition stocks is the CAMDS. Its purpose is to demonstrate new technology and new equipment for the safe disposal of lethal chemical munitions. CAMDS is located at Tooele Army Depot, Tooele, Utah, approximately 60 miles southwest of Salt Lake City. The U. S. Army Toxic and Hazardous Materials Agency (USATHAMA), Aberdeen Proving Ground, Maryland, is responsible for the centralized management and direction of the Army's program for demilitarization of toxic and hazardous materials. Thus, CAMDS has been designed, built, and operated under their purview.

The disposal process begins by separating the chemical agent from the munition. The agent is then pumped to a separate building for

detoxification; explosively configured munitions are sectioned and conveyed to a furnace where the explosives, propellants and any residual agent are burned off. Nonexplosively configured munitions are incinerated to burn off any residual agent.

The facility is designed to detoxify three different chemical agents - but, for safety reasons, only one agent will be allowed in the plant at any one time.

Description of the Agents

Two of the agents to be processed are the lethal nerve agents GB and VX. These agents upset the natural balance between the sympathetic and parasympathetic nervous systems. Casualties result from inhalation of vapors or contact of the liquid on the skin or eyes - either route results in death within several minutes after the fatal dosage is absorbed.

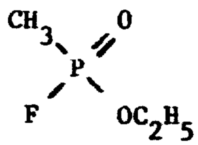
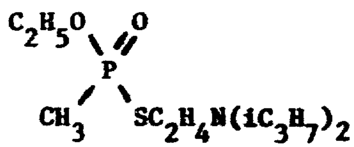
The third agent is a casualty-producing agent called mustard (HD). This agent acts first as a cell irritant and finally as a cell poison on all tissue surfaces contacted. In high doses, it is lethal through skin contact and inhalation; in smaller doses, it is disabling because of blistering and ulceration of exposed tissues.

Table 1 provides some information on the agents.

Processes for Detoxification

All of the neutralization methods employed at CAMDS are basically batch operations. These systems have safety interlocks built-in to prevent possible procedural errors.

TABLE 1. PROPERTIES OF GB, VX AND MUSTARD[3,4]

	GB	VX	Mustard
Chemical Name	O-isopropyl methylphosphonofluoridate	O-ethyl S-2-diisopropylaminoethyl methylphosphonothiolate	2,2'-dichloro diethyl sulfide
Formula			$(ClCH_2CH_2)_2S$
Molecular Weight	140.10	267.0	159.08
Vapor Density (compared to air)	4.86	9.2	5.4
Liquid Density	1.09 at 25°C	1.008 at 25°C	1.27 at 20°C
Boiling Point	147°C	300°C	227.8°C
Vapor Pressure	2.2 mm Hg at 25°C	0.0007 mm Hg at 25°C	0.072 mm Hg at 20°C

Mustard agent will be boiled out of its container and burned in a multi-chamber, semi-continuous hearth furnace. The temperature will be controlled between 600°F to 1200°F relative to the rate of volatilization and type of munition. The volatilized agent is then incinerated in an afterburner at 1600°F and the resultant products are passed to a scrubber system. The incineration reaction of mustard with oxygen in air is [1,2]

$$(ClCH_2CH_2)_2\,S + 6.5\,O_2 \longrightarrow 4CO_2 + SO_2 + 2HCl + 3H_2O$$

Approximately 5 million lbs of mustard has been destroyed by incineration at Rocky Mountain Arsenal in Denver, Colorado.

Nerve agent VX will be destroyed by chlorinolysis in aqueous hydrochloric acid and the resulting acidic solution is then neutralized with sodium hydroxide. The reactor will be controlled to approximately 200°F with cooling water. After the temperature has peaked it will be maintained for 30 minutes to ensure complete detoxification. The acid chlorinolysis reaction is [5]

$$CH_3 - \underset{\underset{OC_2H_5}{|}}{\overset{\overset{O}{\|}}{P}} - CH_2CH_2N(iC_3H_7)_2 + 3Cl_2 + 4H_2O \xrightarrow{HCl}$$

$$CH_3 - \underset{\underset{OC_2H_5}{|}}{\overset{\overset{O}{\|}}{P}} - OH + HO_3SCH_2CH_2N(iC_3H_7)_2 + 6HCl$$

A portion of the acidic solution will be recycled and mixed with fresh acid for the next reaction. Experience to date with the acid chlorinolysis process has been limited to pilot scale quantities.

Nerve agent GB is the only agent to be processed at CAMDS to date. GB is reacted with 18% caustic under controlled feed and temperature conditions. The major reaction is [6]

$$CH_3 - \overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OC_3H_7}{|}}{P}} - F \;+\; 2NaOH \longrightarrow CH_3 - \overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OC_3H_7}{|}}{P}} - ONa \;+\; NaF \;+\; H_2O$$

Figure 1 is a flow diagram for the GB - caustic reaction. 3600 lbs of GB and 12,100 lbs of 18% caustic are pumped into their respective batch tanks. A heel of caustic is added to the reactor and then the GB and the remainder of caustic are gravity fed simultaneously into the reactor until the batch tanks are empty. A cap of 6500 lbs of caustic is then added to ensure at least a five percent excess of caustic after the primary and secondary reactions are complete. The reactant addition, reaction, and agitation steps take approximately two hours to complete.[7] A sample of the resulting brine is analyzed by gas chromatography (GC) for a level of 2.0 nanograms/ml (1.7 ppb) or less of GB and at least 5% excess caustic. After the Quality Control Branch provides a certification that the brine is free of GB, the brine is pumped into a storage tank. A little over 9 million lbs of GB was destroyed by similar means at Rocky Mountain Arsenal.

Bulk Reduction

Certified process waste brines with a low solids content are cycled through an evaporator and are eventually pumped over to two parallel steam

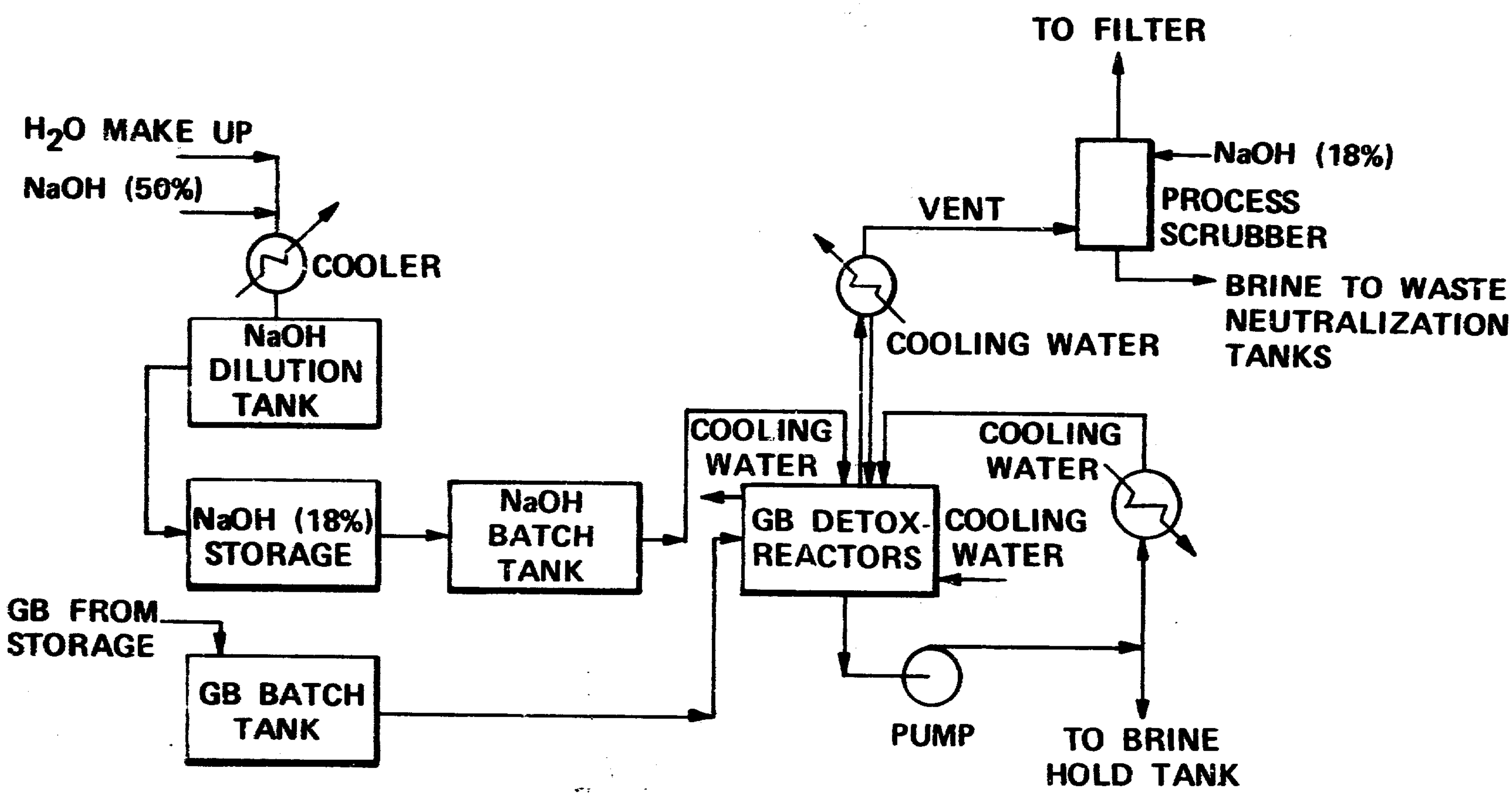


FIGURE 1. GB DETOXIFICATION FLOW SHEET

heated, twin drum dryers. The solids discharged from the dryers are sampled, certified agent free and packaged into plastic lined fiber drums which are then stored in warehouses. The salts generated at CAMDS have been classified by the Department of Transportation as a corrosive (less than class B poison). It is estimated that 1030 tons of salts will be generated during the seven year planned life of CAMDS. Unfortunately, no economically viable market is available for the salt or its individual components. Current plans are to dispose of the salts in a scientific landfill. However, review of other options for utilization of the material will continue to be conducted by USATHAMA.

Environmental Protection

Disposal processes are designed so that they will not have a significant impact on the environment. All of the water used in CAMDS process operations, as well as that produced as by-products of the process chemical reactions, is eventually discharged to the atmosphere in vapor form from the stacks of the drum dryers and the evaporator. Prior to the solutions being evaporated, however, the process streams will be detoxified with sodium carbonate or caustic, analyzed by GC methods, and certified agent free. A small amount of water from the site boiler system and cooling tower will be discharged to a drain system. Since this water does not come into contact with any process streams, it has no opportunity to become contaminated with toxic agents.

All solids are chemically decontaminated to an acceptable level (3X) before removal from a contaminated environment. Any scrap material that is

to be released from government control, or any salvageable material, will be further decontaminated by heat treatment (to 5X) if it has been exposed to any agent or explosive. A typical example would be the GB filled rockets currently being processed:

After draining the agent and cutting the rocket into seven pieces, they are conveyed to an oil fired rotary retort furnace.

In the retort, all energetic material and residual agent is burned off. The pieces have a residence time of 12 minutes at an average temperature of 950°F. The scrap is then deposited onto a steel belt conveyor.

It is then conveyed through an electrically heated furnace to ensure decomposition of any trace amount of agent. Here, the scrap has a residence time of 30 minutes at 1000°F.

The scrap is then discharged onto a conveyor where it is cooled and dumped into containers, sampled, certified free of agent and explosive, and readied for movement off site.

All gases generated in, or passing through, process areas are filtered or scrubbed depending on their origin. Toxic areas where there is a high probability of agent contamination undergo twenty-five air changes per hour. Exhaust air is drawn through charcoal filters (adopted from the nuclear industry); input air is provided so that all toxic areas are under negative pressure with respect to surrounding "clean" areas ventilated at six air changes per hour. The filter train consists of prefilters, high efficiency particulate air (HEPA) filters, activated charcoal filters, a second bank of

charcoal filters, and a second bank of HEPA filters. The blowers are equipped with either adjustable outlet dampers or inlet vanes which will maintain a relatively constant air flow. Each filter bank is provided with gauges to indicate pressure drop across the filters. Sampling ports are provided between the banks of charcoal and in the exhaust stack for continuous monitoring for agent penetration.

The air pollution control systems on the furnaces are designed to clean the flue gases of particulate and chemical pollutants to meet all federal, state and local source air quality standards. Since the systems on the two furnaces are basically identical, only one will be described here.

The flue gases leaving the rotary retort are ducted through a cyclone collector which removes large particles, especially fiberglass, from the rocket parts, and through an oil fired slagging afterburner (1600°F, two seconds) which collects the finer fiberglass particles and destroys toxic vapors. The gases are then cooled by direct contact brine sprays in the quench tower, passed into a variable throat venturi scrubber, a packed bed caustic scrubber and demister to remove the remaining traces of particulate and chemical by-products from the effluent gas stream.

Toxic agent storage tanks and the process chemical storage tanks in the agent neutralization facility are vented into a recirculating counterflow-type packed tower. This caustic scrubbing is to remove any trace quantity of live agent or chemical before delivery to the charcoal filters and eventual release to the atmosphere.

Overall, the pollution control equipment (which includes detection and analysis equipment) have accounted for approximately 19% of the total CAMDS system acquisition cost of $53 million or $10 million. The estimated cost to build another CAMDS is $30 million; of this cost, 30% or $9 million (1980 dollars) would be for pollution control equipment. Operationally, 30% of the CAMDS workforce can be related to support, operation and maintenance of pollution control equipment. This represents a yearly operating cost of $2.2 million (1980 dollars).

Personnel and Process Safety

Safety is, and has been, a key word in the design, construction and operation of CAMDS. Three basic considerations have been to ensure maximum agent surety, complete agent and explosive containment and remote or automated munition demilitarization. Some examples are:

All explosive items are cut into sections or disassembled inside of a 2.5 in thick, air tight, armor plate steel cylinder. This 10 ft by 24.5 ft cylinder has been tested to assure that it will contain the agent and munition fragments in the unlikely event of an explosion.

The rotary retort furnace is designed to withstand an explosion. If it fails, a 15 in thick reinforced concrete barrier which surrounds it will contain any fragments.

Negative pressure and predetermined area ventilation requirements assure agent containment.

A special epoxy coating on building surfaces to ensure easy decontamination in case of a liquid agent spill.

Computer and process interlocks to prevent the inadvertent or incorrect operation of valves, vents, etc.

All personnel onsite must have a standard military issue protective mask and three automatic injectors of nerve agent antidote with them at all times.

All of the operations in the CAMDS toxic areas are remotely controlled from a central control module to minimize personnel entries into toxic areas, adequately control process conditions, and monitor site activities.

Computer outputs, closed-circuit television cameras, direct voice communications, and control panels provide operators with the real-time status of the process. Agent detectors and alarms have remote indicators in the control module so that all personnel on the site can be masked or evacuated within minutes.

Agent Detectors and Operating Limits

Detector and alarm instrumentation is being employed at CAMDS to verify compliance with all applicable gaseous stack emission and working area standards. These instruments provide rapid warning of hazardous conditions, monitor agent concentration levels in toxic process areas and are used to check protective clothing of personnel leaving toxic areas for adequacy of decontamination. The emissions and working area standards (Table 2) for the chemical agents have been set at extremely low levels (nominally in the part

per trillion range) thus requiring technology development which is pushing the state-of-the-art in detection and alarm instrumentation.

TABLE 2. MAXIMUM EMISSIONS AND WORKING AREA STANDARDS[4]

	MAXIMUM EMISSIONS*	MAXIMUM CONTROL VALUE FOR UNMASKED WORKERS**
GB	62 PPT	17 PPT
VX	2.7 PPT	0.9 PPT
HD	4.6 PPB	0.46 PPB
SO_2	500 PPM	

* Based on 1 hour sample time.

** 8 hours per day for an indefinite period averaged over not more than 10 consecutive work periods for GB or 5 consecutive work periods for VX or HD.

The CAMDS agent detectors must perform two primary functions. They must give immediate warning of hazardous situations and they must measure very low level concentrations of agents to guard against cumulative effects over an extended period of time. No single system currently has the ability to fulfill both functions satisfactorily. Therefore, several detector/alarm instruments are employed. These include an M8 alarm with concentrator, the bubbler adsorption system and the real time monitor.

The M8 alarm system was developed in the early 1970's. It is a portable automatic alarm for detection of G and V series agents. The reaction of agent with the reagents in the detector is electro-chemically monitored to

detect agent. This alarm coupled with a concentrator (which is a column packed with 300 mg of porapak P chromatographic column material) can detect agent concentrations in air from 40 ppb to 200 ppt with response times of 1 to 33 minutes respectively. This system is called a DCAC and is used primarily in toxic process areas to monitor the presence of agent which would indicate process upsets.

The bubbler adsorption system is used for sampling G, V and mustard agents. Air is bubbled through a suitable absorbing solution at a known rate for a known period of time. The absorbing solution is then analyzed in the laboratory for the agent. With a one hour sampling period, this method of detection has a sensitivity to the parts per trillion level which satisfies the agent sensitivity requirements for the stacks and working areas. Bubbler data are maintained to provide a record of agent concentration time values in the various CAMDS areas.

The Real Time Monitor (RTM) is based on an enzyme colorimeter method of analysis for the determination of GB and VX. These agents function physiologically as an enzyme inhibitor. Measured quantities of enzymes and reagents are reacted to form a colored species. The analysis is completed by a colorimeter that electronically compares the color intensity of the colored species with a reference. The presence of agent is determined by a reduction in color intensity caused by the inhibition of the enzymes. The RTM detects agents at the required sensitivity (concentrations down to 20 ppt) in 9 to 12 minutes and automatically signals their presence with a local indicator lamp and horn and a remote signal to the control center. All of the electro-

mechanical and chemical assemblies of the RTM are housed in a transportable cabinet. This instrument is currently undergoing extensive testing at CAMDS to develop reliability data. Purchase price of this instrument is currently $35,000.

There is also under development an Automatic Continuous Air Monitoring System (ACAMS) which is based on a gas chromatographic method of analysis for the determination of GB, VX and mustard. Air is sampled through a 10cm · 2mm ID pyrex glass tube containing a Porapak Q or Tenax GC solid sorbent material. After a preset sampling time the sorbent tube is heated and the agent collected in the tube is desorbed onto a GC column to a flame photometric detector. The signal from the GC flame photometric detector is amplified electronically to a strip chart recorder where the peak is recorded. Each peak is quantitated by electronics. If agent concentration during the sample cycle exceeds a preset level an alarm is sounded. Agent detection capabilities have been demonstrated to the low part per trillion level with a less than 15 minute response time. An additional advantage of this alarm is its specificity for the individual agents. Field testing of these systems at CAMDS is scheduled for early 1981. Projected cost for the unit after development is $15,000 to $20,000.

Demilitarization Protective Ensemble

A major new development in protective equipment is the Demilitarization Protective Ensemble (DPE). The DPE was developed in response to the Surgeon

General's direction that during industrial demilitarization operations, such as CAMDS, personnel protective equipment complying with OSHA standards must be used. Since no off-the-shelf equipment was available, a program to develop the DPE was initiated by USATHAMA.

The Chemical Systems Laboratory (CSL) at Aberdeen Proving Ground was selected to develop and evaluate the DPE. The basic approach was to use a NIOSH-approved, positive pressure, air-supplied respirator system inside a protective outergarment. This combination provides both respiratory and percutaneous protection for the wearer.

The DPE consists of three major subsystems

- o Respirator/air support (reusable),
- o Outergarment (single use, disposable), and
- o Communications

ILC Corporation, Dover, Delaware, was chosen as the contractor for the outergarment subsystem. Extensive materials testing was conducted to find the right materials for the visor, glove, and main body of the outergarment. The material had to meet the design criteria of being

- o resistant to chemical agent penetration (liquid and vapor),
- o easily fabricated to the required configuration,
- o relatively inexpensive,
- o able to retain protective properties in the presence of operational fluids within the plant, and
- o rugged enough to pass endurance standards.

The materials chosen as a result of this test were evaluated as to their skin toxicity and irritancy potential. Outergarments were then fabricated and a

series of tests were pursued to establish the design and to evaluate its total system capability. The DPE outergarment consists of a one-piece disposable garment of heat-sealed construction which is closed by heat-sealing after donning. The garment is constructed of chlorinated polyethylene with polyvinyl chloride gloves and a press-polished polyvinyl chloride visor (Figure 2).

The respirator subsystem development began with a survey of commercially available breathable air supply systems to determine if any could be used or adapted for use with the DPE. Mine Safety Appliances Company (MSA) had a model which could be readily adopted if minor configuration changes were made. After redesign was completed, MSA submitted the respirator to NIOSH and subsequently received approval for its use. The respirator consists of a full facepiece, a pressure-demand regulator, a charcoal filter, an air distribution system for cooling of the wearer's extremities, and an auxiliary, self-contained, ten minute air supply for emergency use if the primary air supply fails. If a failure of the primary air supply occurs, then a warning light in the facepiece flashes to alert the wearer.

Breathing and cooling air is provided through a chemical agent resistant rubber hose. Communication cables are attached to the air hose and interface with the DPE communication system via two pairs of electro-optical transducers. There is no physical penetration of the suit material except for the air hose connector. Impermeable toxicological agent protective boots and gloves are worn over the outergarment to complete the ensemble.

The total, integrated system was then tested in the following ways:

o qualitative tests - manned

  human factors evaluation

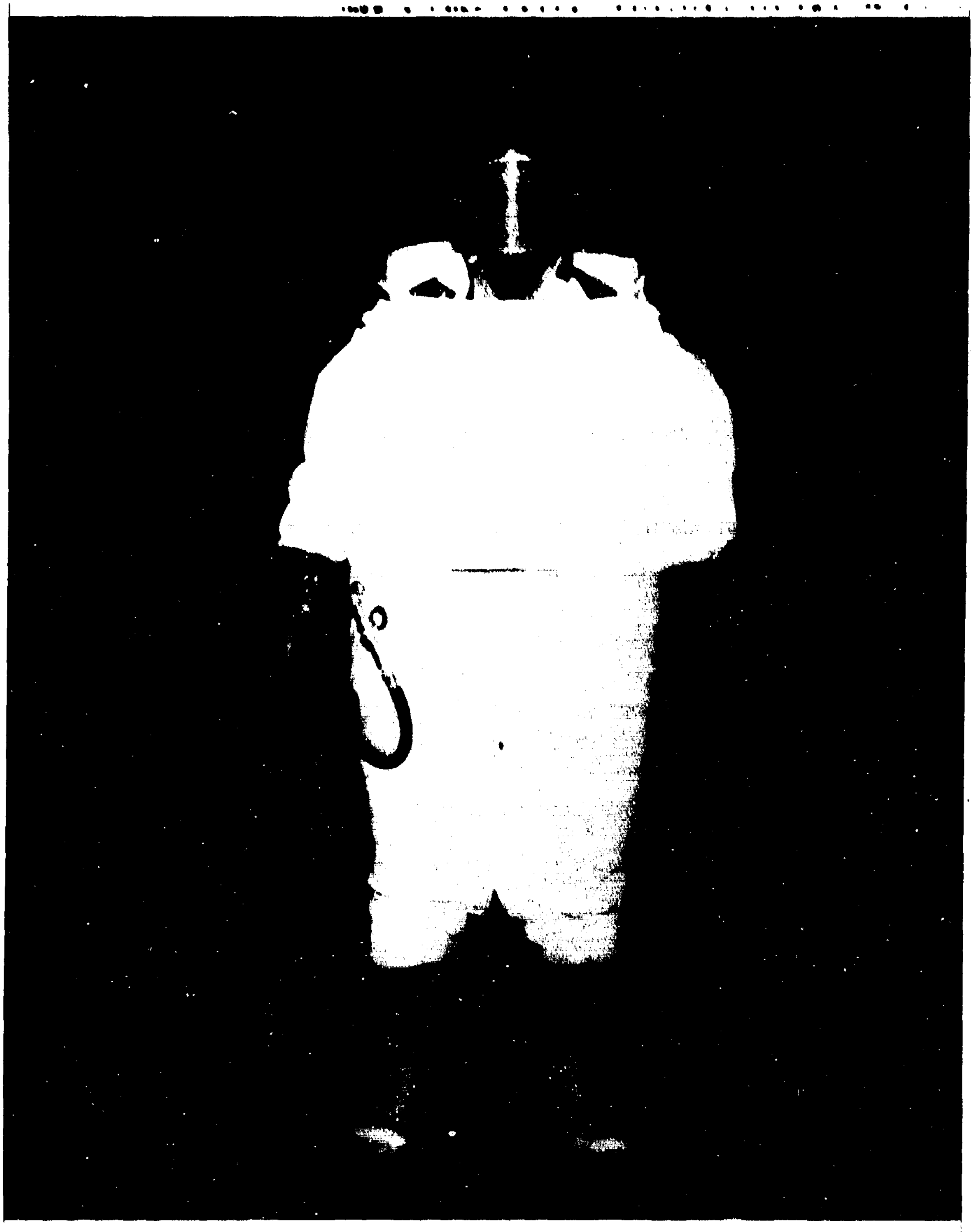


FIGURE 2.

DEMILITARIZATION PROTECTIVE ENSEMBLE

isoamyl acetate trials (banana oil)

endurance trials (no agent)

- quantitative tests - unmanned

    static mannequin trials (agent GB)

    dynamic (articulated) mannequin trials (agent GB)

- quantitated tests - manned

    dynamic pressure trials (no agent)

    10 mg/cu m protection trials (agent GB)

    100 mg/cu m protection trials (agent GB)

A broad training program was initiated in the CAMDS facility to familiarize the workforce with the item and its associated life support system. After review by the Army medical community and the Department of Health and Human Services (formerly DHEW), the DPE was approved for use at CAMDS. In its first year of agent use at CAMDS, over 2000 entries in toxic areas have been made without a single case of agent exposure to a DPE wearer.

Development costs of the DPE have totaled $6 million; production costs are approximately $100.00 for each outergarment. Further refinements to the DPE, such as multiple use options and improved communications, are being evaluated. An adaptation from our DPE work is being developed by the Coast Guard. This suit is for field work or emergency use - it is a zipper-sealed suit with a rebreathing device good for approximately one hour's duration.

Future R&D

Efforts are ongoing to evaluate and develop process improvements to the existing CAMDS. These efforts address both short-term improvements to the

present system and long-term improvements to be incorporated in future demilitarization plants.

Following an extensive evaluation of potential improvements to the CAMDS scrubbing and filter systems, two potential scrubbing alternatives were selected for further testing and development of design parameters particular to the CAMDS situation (dual alkali scrubbing and spray dryer scrubbing). In addition, testing is underway to evaluate the use of lasers to simplify existing methods of munition disassembly (e.g., burster removal and agent cavity puncturing) and munition sectioning prior to further processing in the deactivation furnace. Also, a method of destruction of VX is being investigated in the laboratory for potential use as a decontaminant and as a possible alternative to acid chlorinolysis for destruction of bulk VX. Another study is underway to investigate the use of an induction heating furnace for munition decontamination and agent destruction. The adoption of this process could greatly reduce the amount of effluent gases requiring treatment in downstream scrubbing systems as well as offer savings in energy and operations costs.

USATHAMA is also conducting studies on possible chemical weapon stockpile demilitarization options in the event that such a decision becomes a reality.

Summary

The physical and chemical destruction methods developed at CAMDS will be applied at other locations where there is a need for large-scale demilitarization of obsolete or unserviceable chemical munitions. Environmental and

safety developments will continue to be applied to present and future disposal projects. Of course, process and detector/alarm improvements will be studied to support the overall disposal effort.

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CHEMICAL AMMUNITION DEMILITARIZATION
THE DRILL AND TRANSFER SYSTEM (DATS)

by

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I. INTRODUCTION

Since World War I, the United States has conducted extensive development programs for the design, test and evaluation of chemical munitions. While this country has not employed lethal chemical agents in warfare and is committed not to initiate their use, a number of developed items have been standardized (type classified) and a deterrent stockpile has been maintained.

The munitions in the stockpile are held in various secure storage facilities and are routinely inspected and sampled for deterioration due to latent defects or adverse effects of prolonged storage. These periodic surveillance inspections occasionally discover items with developed defects which permit leakage of the toxic chemical agent. Upon discovery, those items are identified as leaking chemical munitions (LCM), overpacked and segregated in accordance with specific standard procedures. Because of their condition, they impose a substantial storage/surveillance workload burden and, if storage is further protracted, they could become a potential hazard to supply/maintenance personnel. Both considerations prompt an expeditious effort to demilitarize these munitions, recover or detoxify the agents and dispose of the residual materials.

In addition, the weapons development programs have required the use of munitions for various types of tests. Many of the tests have been nondestructive, but involved conditioning or modification which precluded their incorporation into the stockpile of standard munitions. The remaining destructive

tests, principally static or dynamic firing tests, yielded occasional residual rounds (e.g. duds, rockets with expended motors, etc.) which rendered them unserviceable. These have been described variously as recovered chemical munitions (RCM) or as unwanted chemical surety material (UCSM) and have been stored in designated facilities at the development/test and evaluation installations. Storage, security, surety and safety considerations also dictate prompt demilitarization of these items.

Both the condition of the munitions involved and the environmental safeguards policies established by Public Laws 91-121 and 91-441 would make movement of the munitions to a common demilitarization site inadvisable and/or impractical. On the other hand, the relatively small number of items on hand or expected to be generated at each site would make construction of a permanent demilitarization facility at each installation grossly cost ineffective. The adopted resolution of this dilemma was to provide a transportable system with a tolerant configuration, capable of processing all types of munitions of interest with the same equipment and which could be set up for operations in a readily available field site at each installation.

To meet this requirement, the US Army Toxic and Hazardous Materials Agency developed the Drill and Transfer System (DATS). The DATS provides a safe and environmentally acceptable capability to drill into the agent cavity of a chemical item, drain the agent therein into a container suitable for long term storage or shipment, and decontaminate all material and equipment involved. It is important to note that while the munition is "demilitarized" the agent contents are not destroyed. This concept reduces the extensive equipment requirements necessary for the safe and efficient detoxification of agent while still eliminating the problems and hazards associated with long term storage of leaking items and possibly deteriorated range items.

The necessary transportability specification has been integrated into the system design thus eliminating the concerns for costly replication of demilitarization systems and enabling the DATS to sequentially operate at various sites. After the current backlog is processed, repeat visits will be conducted, as necessary, to dispose of newly discovered items at specific sites.

The flexibility to process a wide variety of munitions and agents has also been incorporated into the DATS. Typical chemical items which must be processed (Figure 1) range from projectiles and rockets up the MC1 750lb GB Bomb. Agent types will be predominantly GB, VX and mustard although the DATS can safety process all standard liquid agents. Both explosively and non-explosively configured items will be processed.

II. SYSTEM DESCRIPTION

The DATS is a low production system designed to handle a limited number of unpackaged or overpacked munitions. The most critical element of the system is a glovebox (Figure 2) in which the munition is drilled and drained of agent. The glovebox is a stainless steel cabinet, mounted on a structural steel frame, which has a cross sectional area large enough to process an 8-inch projectile in an overpack and enough length to unpack an M55 rocket from an overpack. The glovebox is approximately 32 feet long, 5 feet wide and 9 feet high. Window panels placed along the length of both sides provide full visibility to the process chamber. Seven pairs of gloveports fitted with butyl rubber gloves are located in the windows on each side. These provide convenient access to all normal processing stations and other areas without opening the box.

Transport/holding devices mounted on track conveyors are incorporated into the glovebox to move the munitions from the loading door to the drill and drain stations and to support them in the proper location for drilling and draining. Three hoists are provided to facilitate handling the munitions and containers.

TYPICAL DATS ITEMS

– 115MM ROCKETS	– 4.2 INCH MORTAR ROUNDS
– 105MM PROJECTILES	– M23 LAND MINES
– 155MM PROJECTILES	– MC-1 750 LB BOMBS
– 8 INCH PROJECTILES	– MK94 500 LB BOMBS

Figure 1

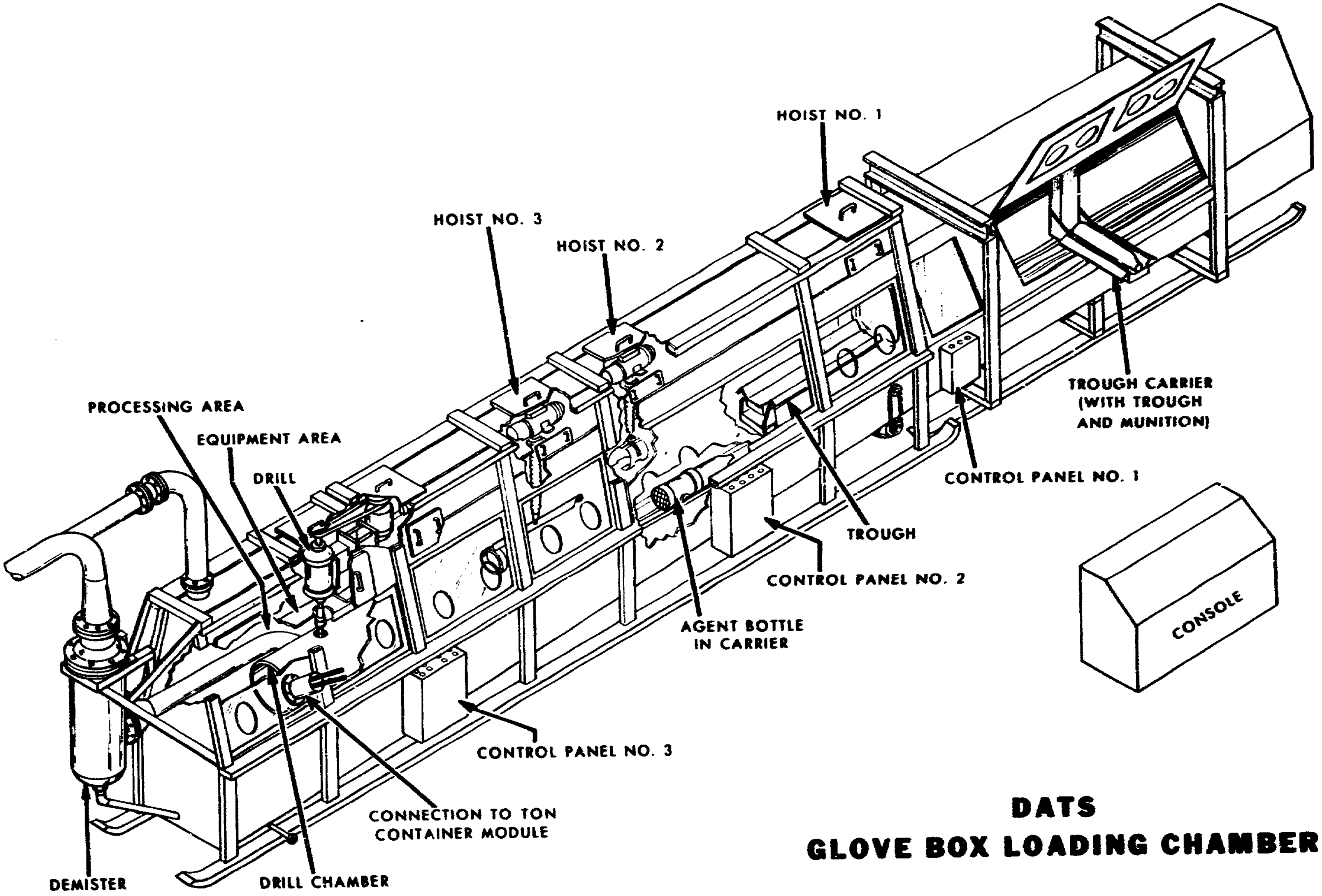
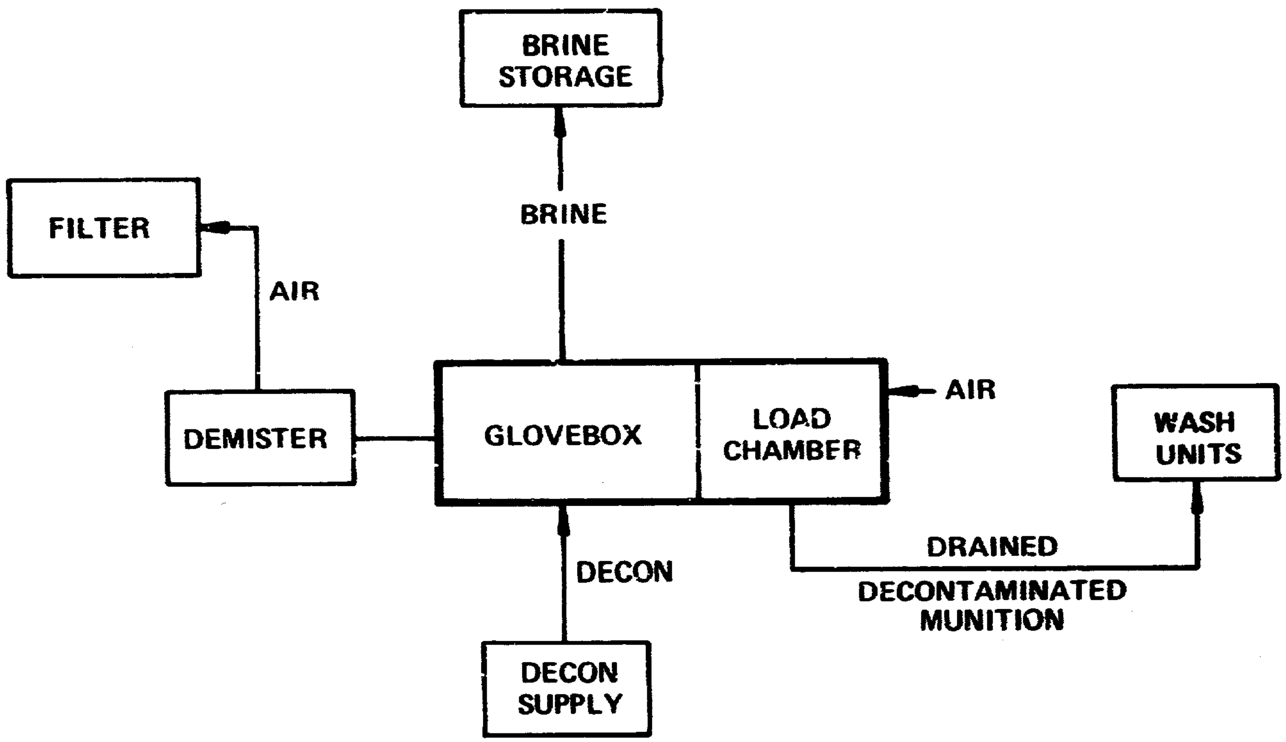

HOIST NO. 1
HOIST NO. 3
HOIST NO. 2
TROUGH CARRIER (WITH TROUGH AND MUNITION)
PROCESSING AREA
EQUIPMENT AREA
DRILL
CONTROL PANEL NO. 1
TROUGH
CONTROL PANEL NO. 2
AGENT BOTTLE IN CARRIER
CONSOLE
CONTROL PANEL NO. 3
CONNECTION TO TON CONTAINER MODULE
DEMISTER
DRILL CHAMBER
DATS
GLOVE BOX LOADING CHAMBER

Figure 2

A metal chamber encloses the munition during drilling to minimize agent dispersion. A removable section in the top of the drill chamber provides emergency access and is made of clear plastic so that the munition drilling operation can be observed by video camera.

A loading chamber is attached directly to the glovebox. The loading chamber is of similar construction to the glovebox and is primarily designed to provide a separate compartment, relatively free of liquid decontaminants, which serves as a vestibule for loading munitions into the presumable contaminated glovebox and for sampling items for agent contamination before removal to the atmosphere. The loading chamber is large enough to accept any item which can be accommodated by the glovebox. It is equipped with a remote controlled carrier for loading and unloading the munitions. The only entry and exit of material to and from the glovebox and loading chamber is through the loading chamber. The doors of the glovebox and loading chamber are interlocked to prevent the loss of negative pressure within the glovebox which would occur if both doors were opened simultaneously.

A number of support modules (Figure 3) are integral to the system and perform auxiliary functions in support of the glovebox. These include a charcoal filter unit which ventilates the glovebox and loading chamber, maintains a negative pressure within each and removes agent from exhaust air prior to release to the environment. Other modules include a decontaminant supply module which provides decontaminant for the system; brine holding tanks where agent decontaminant is held pending certification; wash units where drained munitions are submerged and washed with decontaminant to assure all internal surfaces are free of agent; and a ton container (TC) module (Figure 4)



DATS EQUIPMENT SCHEMATIC

Figure 3

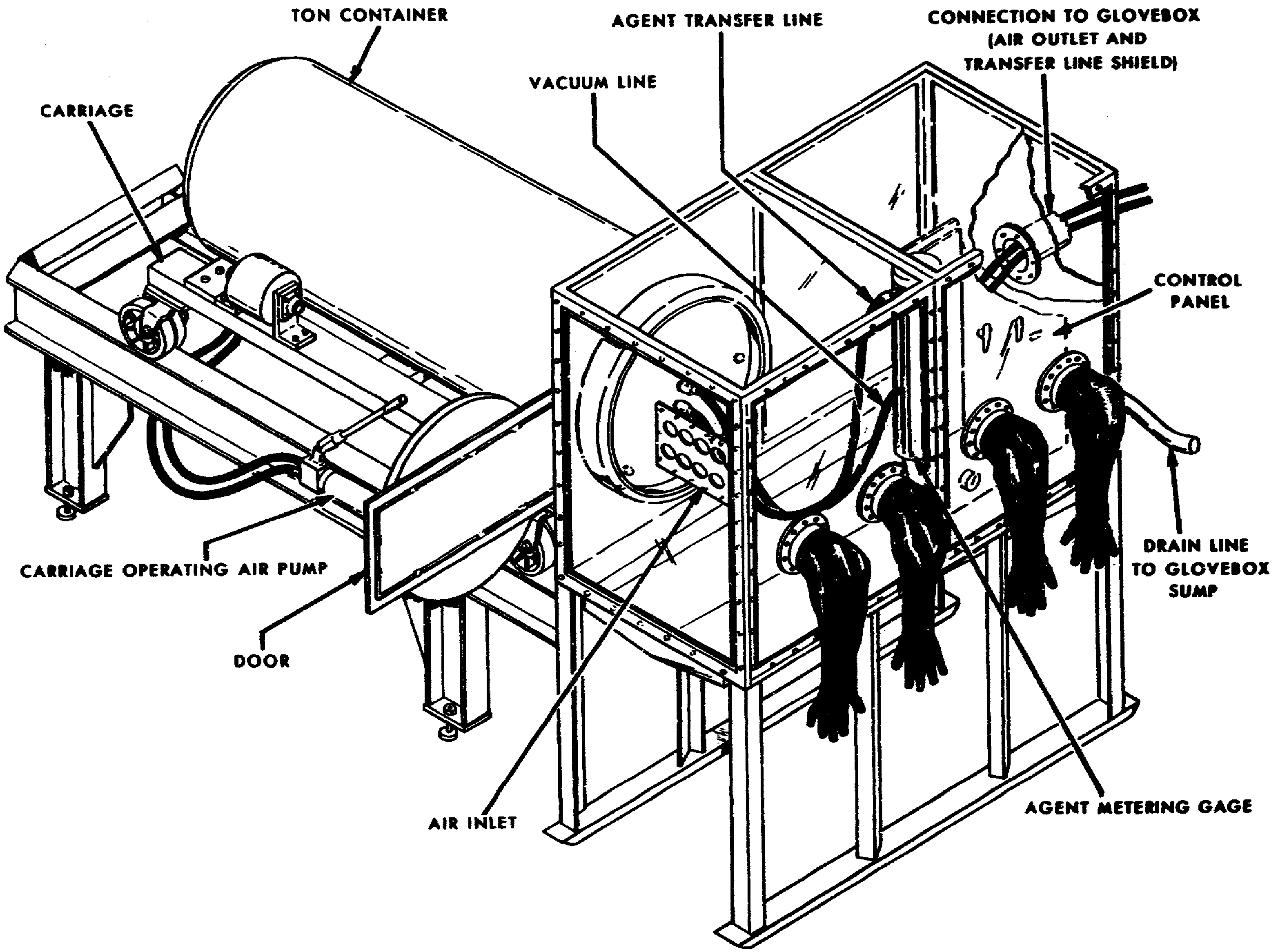

TON CONTAINER
AGENT TRANSFER LINE
CONNECTION TO GLOVEBOX (AIR OUTLET AND TRANSFER LINE SHIELD)
VACUUM LINE
CARRIAGE
CONTROL PANEL
CARRIAGE OPERATING AIR PUMP
DOOR
DRAIN LINE TO GLOVEBOX SUMP
AIR INLET
AGENT METERING GAGE

Figure 4

which enables agent to be drained into a TC. Shortly to be developed is a large item module where items larger than 8-inch projectiles are drilled and drained.

A typical DATS operation site is shown in Figure 5. The operational site is divided into two distinct areas. The munitions processing area contains most of the above mentioned equipment for processing munitions as well as a munitions holding area and the transportable chemical laboratory. A security and first aid station is emplaced along the fence and forms part of the boundary. The control and support area bounds the fenced processing area. It contains mechanical support modules, including generators, air compressors and decontaminant supply; the Command Post; personnel support modules including a changehouse, crew trailer and maintenance/supply van.

III. PROCESS DESCRIPTION

Figure 6 shows a process flow diagram for the DATS operation. Major operational steps include transport of munitions, munition processing in the glovebox, munition processing in the wash units and disposition of the various process residues. These are discussed in detail below:

Munition Transport: Only the quantity of munitions to be processed daily are moved from the storage area to the munitions holding area. At the end of each workday, items not processed are returned to the storage area along with the containers of agent drained during the day. Movements in both directions are by truck convoy, accompanied by security escort, a decontamination truck, and an ambulance manned by qualified medical personnel. The convoy movement terminates at the munitions holding area. A vehicle assigned to the

GENERAL DATS SITE LAYOUT

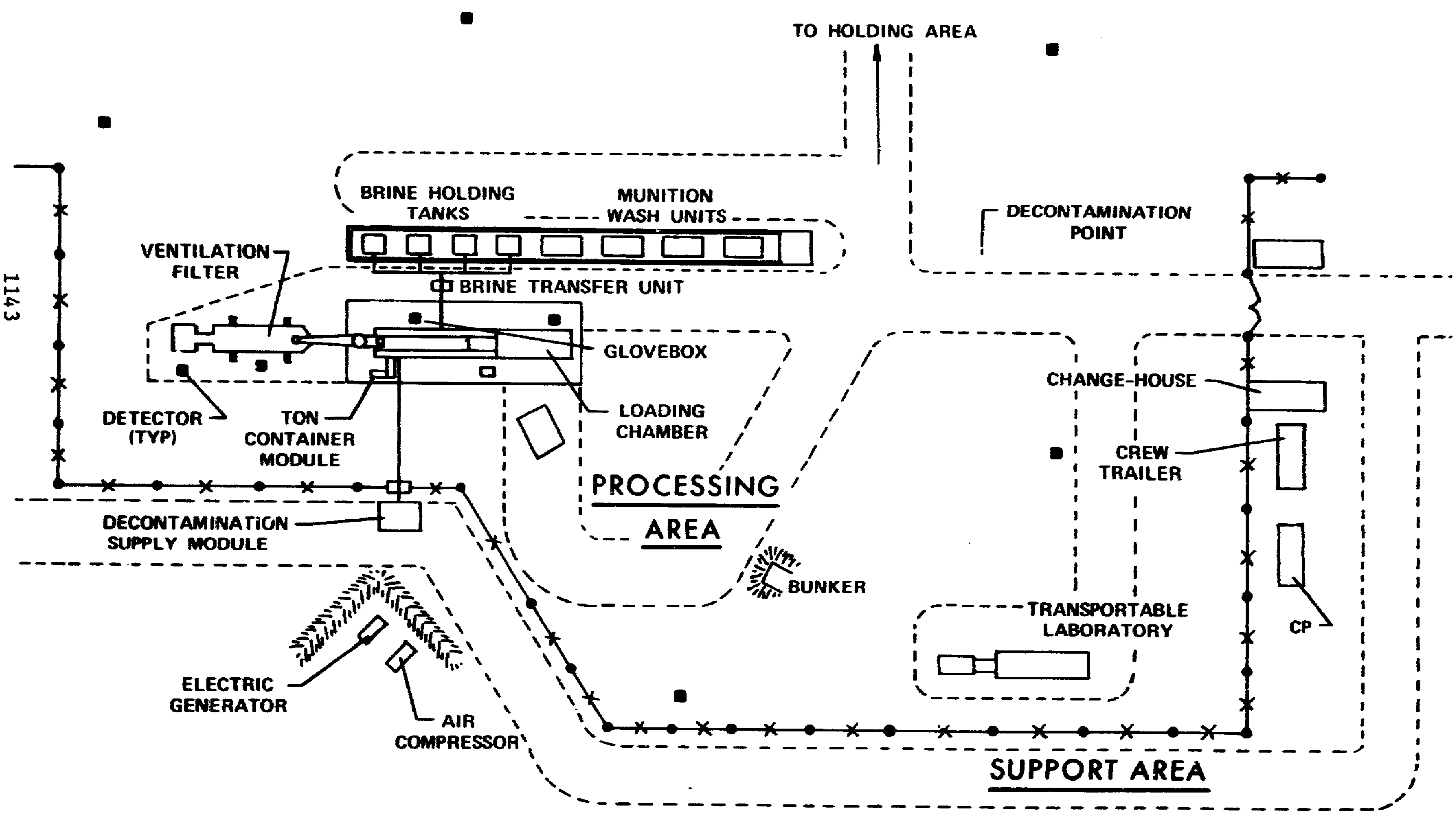
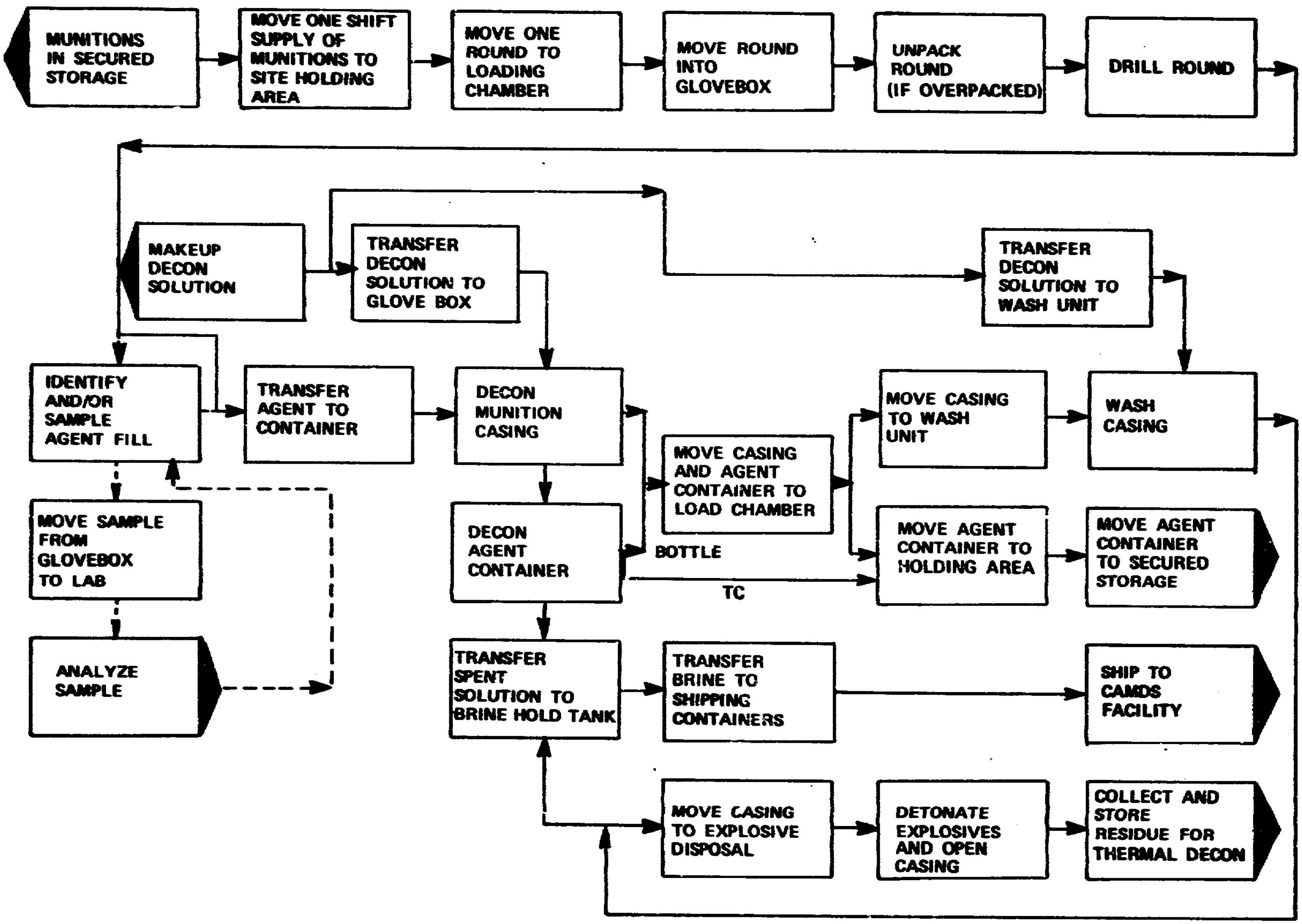


Figure 5



DATS OPERATION

Figure 6

operations area picks up the munitions and moves them to the loading chamber. The vehicle also moves the containers of drained agent from the loading chamber to the munitions holding area where they are stowed to await convoy pickup at the end of the workday.

Glovebox Processing: The munition is placed on a tray located on a powered carrier in the loading chamber, and the loading chamber door is closed. The door between the loading chamber and the glovebox is opened, and the carrier and tray containing the munition are moved into the glovebox. The carrier is then returned to the loading chamber and the door separating the loading chamber from the glovebox is closed. A clamp and support blocks are used to secure the munition to the transport table. A powered conveyor system moves the munition into the drill chamber.

When the round is in position, the glovebox operators are moved to a prepared position and signal the Command Post that the munition is ready to be drilled. The project officer in the Command Post then enables the programmed drill operation. A TV monitor provides visual observation of the drilling sequence. When the drill penetrates the shell cavity, the drill is automatically retracted.

Upon completion of the drilling operation and clearance from the Command Post, the glovebox operators initiate agent transfer. The agent is transferred to either a three gallon DOT 3A bottle or a ton container (TC) by a vacuum transfer system. The choice of container is dependent upon the quantity of agent anticipated to be accumulated during operations. The smaller DOT 3A bottle is located inside the glovebox. The glovebox operators attach an agent transfer tube to the container and insert the other end of

the transfer tube into the munition agent cavity. A vacuum line is also attached to the container and a vacuum pump is activated to transfer the agent into the container. The transfer tube in moved about the inside of the munition cavity to extract as much of the agent fill as possible. As soon as all possible agent has been extracted from the muntion, the vacuum pump is deactivated, and the transfer tube is removed from the agent cavity.

Upon completion of agent transfer, the agent cavity of the munition is flushed with decontamination solution by means of a supply tube inserted into the agent cavity. The operator selects the appropriate decontaminant (Na_2CO_3 for GB; $Ca(OCl)_2$ for mustard and VX) and activates the flow control switch at the console causing the decontaminant to be pumped into the empty round. The cavity is flushed and an overflow condition is maintained to promote thorough rinsing of the cavity. The decontamination supply is shut off, the tube removed from the munition, and the transport table conveyor activated to move the munition from the drill chamber. This action simultaneously activates a programmed decontamination cycle in which fixed nozzles spray the outside of the munition with decontaminating solution during passage from the drill chamber.

The drilled hole is then sealed with a snap-tight adjustable plug after the munition is removed from the drill chamber. The munition is lifted clear of the table, washed with decontaminant and rinsed on the exterior by an operator using a hand wand, and then loaded onto the carrier tray by means of hoists. If the DOT 3A bottle has been used, it is also conveyed to its transport-out position beside the carrier tray, washed with decontaminating solution and rinsed. The munition and bottle, if applicable, are then removed from the glovebox back into the loading chamber by reversing the glovebox charging procedure described previously.

The munition and overpack are monitored for agent contamination using the M18A2 Chemical Agent Detector Kit and the M8 Chemical Agent Alarm with concentrator as applicable. Only when the sampling indicates no detectable contamination are the materials removed from the loading chamber.

Munition Wash Unit Processing: The munition and overpack are removed from the loading chamber after certification by munition handlers. The items are then submerged beneath the appropriate decontaminant in a wash unit designated by the project officer. The adjustable plug is removed and a flush probe from the recirculating pump mounted on the wash unit is inserted into the munitions cavity through the drill hole. After flushing for an extended period of time, the munition is then sampled for residual agent. This is accomplished by draining the munition, washing the munition cavity with a small amount of chloroform and then analyzing the chloroform for agent. In conjunction with this, a sample of brine from the wash unit is also analyzed for agent. When negative results are received from the laboratory, the munition is removed from the wash unit. Similar procedures are followed for overpacks.

Hardware Disposition: All munitions are subjected to explosive detonation with supplementary explosives. This is accomplished to destroy explosive components and to heat treat the metal. The demolition operations are accomplished on a batch basis by Army Technical Escort Unit EOD personnel. Fragments from the demolition are collected and placed in interim storage pending movement to a thermal decontamination facility.

Brine Disposition: Brine generated at the glovebox is pumped to the brine holding tanks from the glovebox sump at the completion of daily operations. Brines from the wash units are pumped to the brine holding tanks after certification

of all hardware in the particular unit or if agent is detected in the brine during munition certification. When the tanks have insufficient capacity remaining to accept the expected brines from the next scheduled operation, a sample of the brine is drawn and taken to the laboratory for analysis. If the analysis reveals that contamination remains, additional full strength decontaminant is added, and the brine recirculated and resampled. After the analysis verifies that detectable agent is no longer present, the brines are drained into a polyethylene-lined 55 gallon drum and moved to an interim storage area pending transport of the brines to a drying facility at the end of the installation operations.

IV. PILOT TESTING (PHASE I DATS)

At the outset of the DATS Program, a decision was made to pilot test the system at Dugway Proving Ground (DPG), Utah, prior to operating at installations in more populated areas. DPG was selected due to its remote location and because the types of munitions requiring demilitarization at DPG were representative of many of the items to be processed at other locations. The pilot test was designated as Phase I DATS and all follow-on operations were included in Phase II DATS.

Phase I DATS was conducted at DPG in the fall of 1979. The objectives of the pilot test included the following:

To demonstrate the capabilities of the DATS equipment and to identify problems which must be resolved before operating at Phase II sites.

To determine the adequacy of operating procedures and to provide the basis for revision prior to Phase II operation.

To provide training for Technical Escort Unit (TEU) personnel who will provide the cadre for the Phase II operating team.

To dispose of the 60 chemical items recovered at Dugway Proving Ground.

The munitions inventory which was designated for demilitarization during Phase I DATS consisted of a number of munitions which had been recovered from the various test and holding areas at DPG. Many of the items were badly weathered and had illegible nomenclature markings. In order to further characterize the munitions and to determine which were compatible with the DATS, two munition assessments were conducted.

During the first assessment, conducted December 1975 - April 1976, 161 potentially toxic filled munitions located at the Tower Grid and West Granite Holding Areas of DPG were evaluated by examination, x-ray and weighing. Also, fuzed munitions not verified as being safed were subjected to standard EOD safing procedures. At the conclusion of the first assessment 64 items had been included in the potential Phase I DATS inventory. The remainder were found not to contain lethal chemical agents or were incorporated into other demilitarization programs. Subsequently, two additional items were found, increasing the inventory to 66 items.

A second, more exhaustive assessment conducted in September 1977, resulted in a final DATS inventory of 60 items. These items included projectiles, 4.2-inch mortar rounds, 115mm rockets and warheads, and bomblets. All of the rounds, except the bomblets and a small number of artillery rounds, included explosive components. Two mortar rounds were fuzed as well, but the fuzes were unarmed with safety pins in place. All, except one of the rocket motors were spent. The indicated agent fills included GB, VX, and mustard as well as possibly simulants and white phorphorus.

Prior to operations at DPG, a series of nonagent tests were conducted on site in order to train operators and to demonstrate to safety and reviewing personnel that the system was ready for agent operations. These tests included a checkout test to demonstrate that the equipment had been properly installed; a system test to provide full scale training; and a final simulant pilot test to obtain additional data for reviewing agencies and to serve as a vehicle for the USATHAMA Preoperational Safety Survey. The preoperational survey was completed in September 1979, and all findings were rectified prior to the startup of operations.

The first munition was drilled on 22 October 1979, and the last, the 60th item, was drilled on 6 December 1979. Figure 7 summarizes the results of the Phase I pilot test. In general, all major test objectives were accomplished. More importantly, no operator exposures were experienced and air monitoring of the operational site indicated that no agent release had occurred during operations. Furthermore, no problems were encountered which compromised the environmental and safety aspects of the DATS. A number of minor equipment problems were incurred which limited the production rate to approximately three items per operating day against a design rate of five per day. Additionally, severe winter weather was encountered in early November which necessitated winterization of the system. As a result of these findings, an equipment modification program for the DATS was implemented and will be completed before Phase II operations are initiated.

An additional problem, that of solid mustard residues, was also encountered during the October - December operations. Nine mustard munitions were processed at DPG. All were found to contain varying amounts of solid residue. The

DATS PHASE I MUNITIONS

	QUANTITY OF MUNITIONS DRILLED						
FILL TYPE	105MM	155MM	8"	4.2"	M55/M56	BLU-19	TOTAL
GB	15	7	3	–	–	4	29
VX	–	–	12	–	7	–	19
H	2	5	–	2	–	–	9
SIMULANT	–	2	–	–	–	–	2
WP	–	–	–	1	–	–	1
TOTAL	17	14	15	3	7	4	60

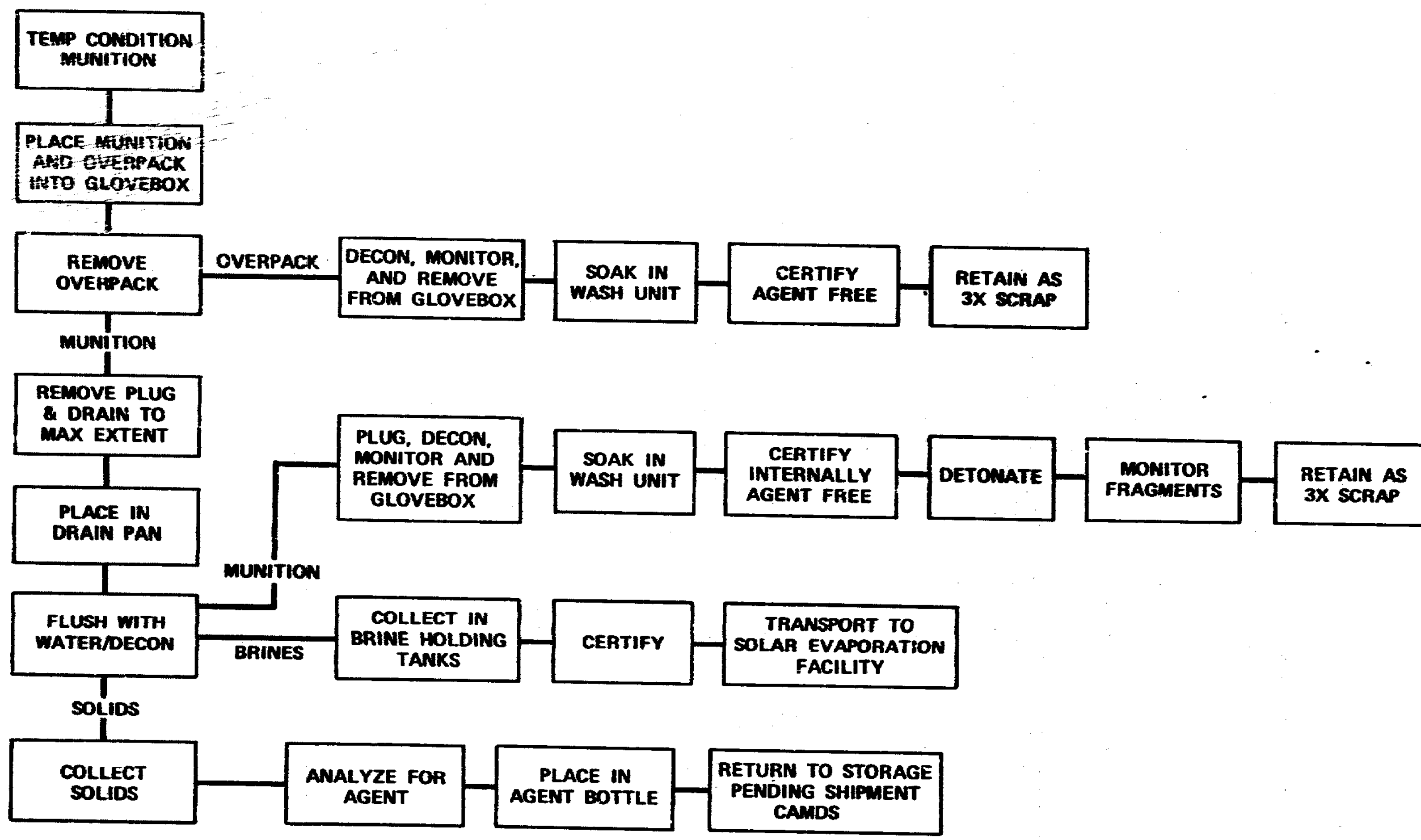
Figure 7

ambient conditions at DPG were such that the residues could possibly have been frozen mustard agent. However, analysis of residue samples in the laboratory revealed that frozen mustard was extensive in only two munitions. The remaining items contained a solid residue which was thought to be polymerized mustard and/or elemental sulfur, an impurity in Levinstein mustard. Several solvents were tested in an attempt to find a means for dissolving the residue to permit its removal by draining. The material proved to be highly insoluble in all the solvents tested. It was found, however, that the residues could be removed by agitating the solids with HTH solution ($Ca(OCl)_2$), the decontaminant for mustard. This finding providing the basis for the procedures adopted.

The concept selected incorporated a recirculating stream of HTH to erode/dissolve the mustard residue. The procedures required heat treatment of the munition to 145°F to melt any frozen mustard present followed by draining or verification that the munition could not be drained and flushing with recirculating HTH solution. After removal of the solids was verified by volumetric techniques, the munition was processed through the wash units, verified as being agent free and detonated. A process flow diagram and equipment schematic are shown in Figures 8 and 9. In this manner all remaining mustard rounds were successfully emptied of their contents during 25-28 February 1980, thus completing the final processing of all Phase I items.

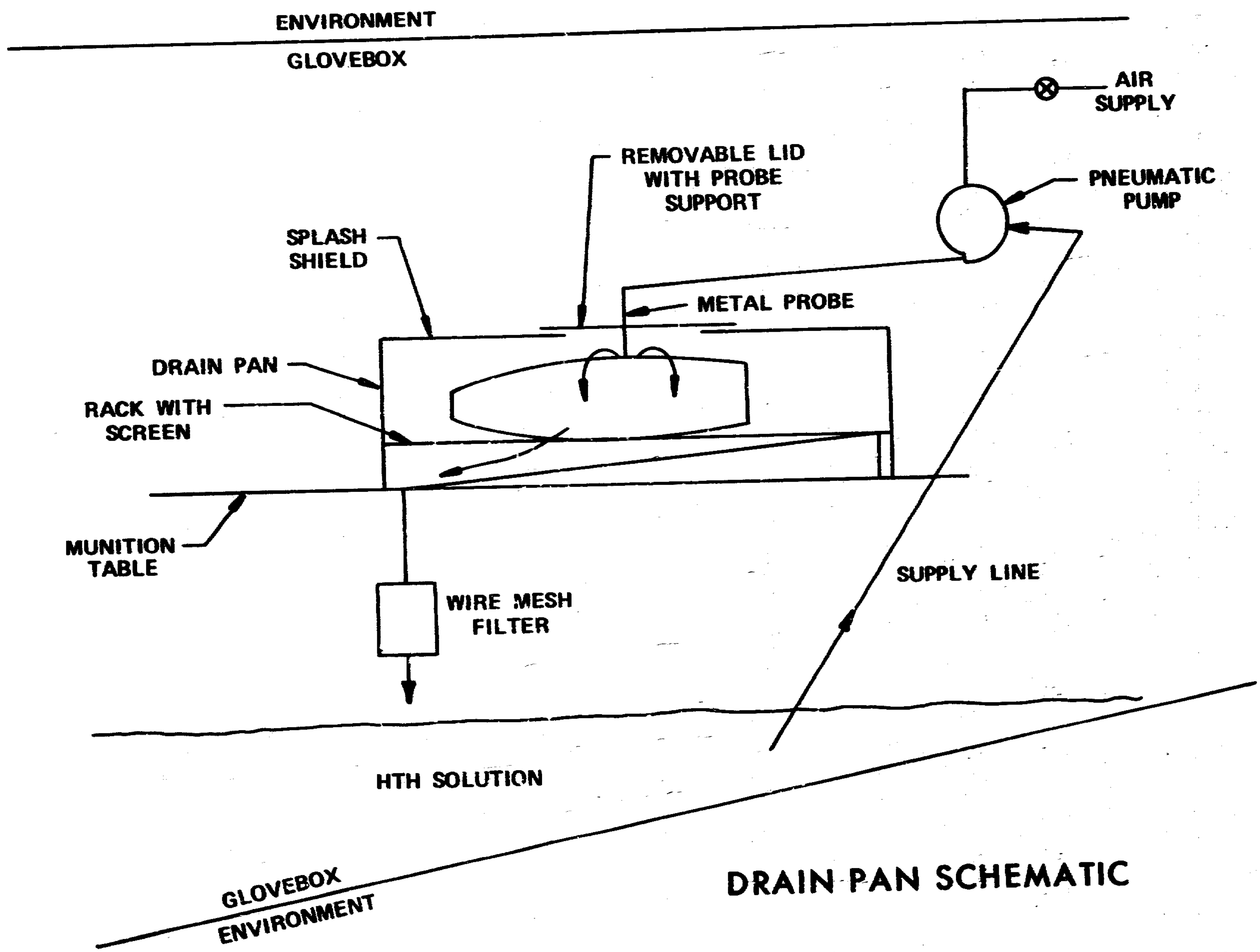
V. REMAINING MISSION (PHASE II DATS)

Preparations are currently underway for the conduct of operations at other DA installations. The additional sites in scheduled sequence and the projected DATS Phase II workload are shown in Figure 10. The DATS is scheduled



RESIDUE REMOVAL PROCESS FLOW

Figure 8



DRAIN PAN SCHEMATIC

Figure 9

PHASE II DATS

SITE	MUNITION QUANTITY
PINE BLUFF ARSENAL	38
ANNISTON ARMY DEPOT	36
LEXINGTON-BLUE GRASS DEPOT ACTIVITY	54
ABERDEEN PROVING GROUND	130
UMATILLA DEPOT ACTIVITY	67
PUEBLO DEPOT ACTIVITY	54
JOHNSTON ISLAND	16
TOOELE ARMY DEPOT	659
TOTAL	1054

Figure 10

to visit eight sites over the next five years and with the exception of Aberdeen Proving Ground, Maryland, all are DA storage installations where leaking chemical munitions will be processed. At Aberdeen Proving Ground items recovered from test and storage areas rather than leakers from stockpiled materiel will be processed.

In preparation for these operations, the DATS glovebox and support equipment are being permanently mounted on trailers to facilitate ease in transporting, setting up and shutting down. Also, the trailerization of equipment will permit the incorporation of an all season capability for the DATS. This task along with other minor modifications to the DATS will be completed in time to begin operations at the first Phase II site, Pine Bluff Arsenal, Arkansas, in early CY 1981.

BLAST PROTECTION VALVES - REQUIREMENTS AND TEST METHODS

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Let us start with a definition:

With Blast Protection Valves I shall mean valves mounted in inlets and outlets for gaseous products to protect a hardened structure

- permitting continuous flow with a moderate loss of head

- prohibiting at least the substantial part of a transient blast wave to enter the installation.

The valves can be used in sheltered areas, aboveground as well as underground, or in explosives storages where an accidental explosion can occur in the neighborhood.

Triggering of the valve closure can be arranged in different manners. Manual closing might be feasible for alert situations in manned shelters but hardly for cases where accidental explosions are taken into consideration.

So we may have to turn to automatic closing, using some effect of the actual blast we want to protect our installation against.

Sound effects can be outruled at once as the blast wave at interesting pressure levels is supersonic. Using the flash could be another solution, e.g. through remote light-sensitive sensors. You then, however, must have a permanent, reliable optical sight and protect the communication lines between sensors and valves.

The safest way may thus be to use the hazard you want to protect against in itself, i.e. the blast.

Schematically such a valve consists of a mechanical device so arranged that the blast overpressure activates its closing. In principle some sort of spring keeps the device in open position during normal ventilation conditions, but at a certain overpressure level the spring force is overruled which results in closure.

Some designs allow a small amount of the blast to seep through during closing time while others use some sort of ingenious detour system to block up the blast effects totally.

Let us discuss some factors of importance when choice of valve for some special purpose is considered. We will have a look at, without grading their mutual

importance, the following qualitites:

- The ventilation function
- The protective function
- Mounting
- Maintenance
- Cost

The ventilation function

The volume of air possible to suck in or blow out through a valve is of course a main feature. It is determined by the gross dimensions of the pipes and tolerable loss of head over the valve.

Tolerable pressure drop is of course dependent on loss of head in the complete system and fan capacity. Actually this can create a vicious circle: To overcome a certain flow resistance you might need a certain fan, requiring a certain volume of air for cooling which might force you to chose a more powerful fan requiring still more air for cooling etc.

Furthermore noise problems may very well set the limit for the volume of air which you can practically treat in your system.

Apart from possible calculational intricacies the data on ventilation function are quite straight-forward and easy to handle.

The protective function

What data to use to illustrate the protective function is a somewhat more intricate problem.

Of course the sustainable blast overpressure level should be in concordance with the rest of the hardened structure in which the valve is installed. Whether this pressure is side-on or reflected depends on geometry.

The valve should preferably block up the suction phase too. Though the underpressure is limited in magnitude it can cause substantial damage due to the fact that it acts in the "wrong" and often disregarded direction.

Of importance might also be the lowest overpressure which activates the valve when the pressure-time history involves a long duration. In such cases even a low overpressure may contain a substantial impulse density.

The impulse let through during closing time should of course be as small as possible and definitely not higher than connected installations behind the valve could stand.

Other questions in this connection are whether the valve should be able to stand multiple bursts with unaltered function and whether a short stop in the flow of air after the blast can be tolerated. The latter might be relevant in cases where the return mechanism has difficulties to fulfil its intended function when disturbed by an airflow.

Mounting and maintenance

An attractive valve should naturally be possible to mount without any great efforts or special tools. Weight is here of course of essential importance. Space occupied by the installation may also be considered.

Demounting possibilities might also be of interest in case you want to exchange parts of the valve for some reason.

For maintenance reasons stainless or at least corrosion-protected valves are to be preferred. Moreover easy access to the different parts of the installation facilitates necessary maintenance operations as well as routine inspections.

Cost

Once you have decided to use a hardened structure you have already made the main step as far as cost in concerned. The additional cost of valves is definitely of minor importance and adds but marginally to the total cost. Of course I in this respect disregard any fancy system with independent computer systems, loads of remote sensors etc.

Testing

Tests should be performed under as realistic conditions as possible. This implies that the tests should be made on full-scale specimens, i.e. the valve should be in full scale while the rest of the structure can be simulated under the assumption that the real structure will remain intact and rigid at the nominal blast pressure.

At a really realistic test the ventilation function should be switched in at full capacity. Furthermore the incident blast wave should contain nominal front pressure, prescribed duration and suction phase. To this the lowest pressure at a long duration load which activates the valve should be established.

Measurements should be made recording the pressure-time history of the incident wave as well as the one let through during closing time (if any). Furthermore pre- and post-shot ventilation air flow should be checked.

Efficiency factor

Technical data of primary importance are measures of the protective and ventilation functions respectively. The protective function may for instance be illustrated by the impulse let through. This should be as small as possible.

Ventilation capacity may be illustrated by the air flow capacity in m3/h. This should be as large as possible.

So we can form an "efficiency factor" as the ratio between let through impulse and ventilation capacity. The impulse is easily calculated as the let through reflected impulse density times the area of inlet tubes and can be measured in Ns (newtonseconds). Ventilation capacity is measured as volume of air in m3/h.

Of course no theoretically justified level exists for such a factor. Empirical experience might, however, give some idea on the order of magnitude. Quite naturally the acceptable value should depend on the protection level expressed as the maximum tolerable blast overpressure.

We can tentatively use the following data where incident pressure as well as let through impulse refers to reflexion values.

Thus the above defined efficiency factor **should not exceed the following values:**

Incident overpressure	MPa	.2	.5	1	2	5
Efficiency factor	$\frac{Ns}{m3/h}$	1.25	2.	2.75	3.5	4.

This factor should primarily be regarded as a tool for the decision maker when comparing different makes of valves. For design of equipment placed behind the valve the true let through impulse should of course be used.

ORIGINS AND IMPLICATIONS OF UNDERGROUND STORAGE REGULATIONS

By

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INTRODUCTION

This study was part of the Navy Shore Facilities Exploratory Development Program which is sponsored by the Chief of Naval Material through the Naval Facilities Engineering Command. It is the first part of an effort to evaluate the economic and operational feasibility of underground explosives storage for the Navy. The effort is coordinated with but is not an integral part of the Navy Explosives Safety Facilities Project.

The Navy is unique among the Services in that most of its operational explosives storage facilities must be located on or near the waterfront in order to effectively serve the Fleet. Real estate in these areas is both rare and expensive. The Navy must therefore consider measures such as underground storage to reduce the proportion of that valuable area whose use is severely restricted by explosive safety quantity-distance (ESQD) arcs. This study will help to determine the extent to which the encumbered land area can be reduced within present regulations, and will identify critical factors where research could lead to further savings. The impact of underground storage on operations and maintenance requirements will also be studied. As a first step in this effort the origins and implications of the present underground storage regulations were reviewed.

This paper presents what is essentially the state-of-the-art for underground explosives storage at the time of this study. Specifically, Section 5-8 of NAVSEA OP-5 (Ref 1) is discussed and evaluated with respect to the technological data base on which regulating equations were based. Although this regulation relates specifically to explosives storage in Navy facilities, it is virtually a verbatim transcription of the Department of Defense (DOD) regulations (Ref 2). The DOD regulations were, in turn, derived from NATO regulations that predated them (Refs 3 and 4). Equations found in both sets of regulations are the same except for the units and coefficients. This text uses U.S. customary units as the primary system to be consistent with References 1 and 2. However, NATO and other European data are frequently referenced, and data and equations from those sources will be expressed in both International System (SI) and U.S. customary units. The text employs the generally accepted nomenclature of using W when the net explosive weight is in pounds and scaled distances are in feet for U.S. customary units, and Q when the next explosive quantity is in kilograms and scaled distances are in metres for SI units.

CHAMBER SEPARATION REQUIREMENTS

Separation distances between underground chambers used for explosives storage are specified in terms of the distance required to prevent communication of an explosion and in terms of the distance required to prevent damage to explosives in adjacent chambers. This section discusses the origins and supportive experimental and analytical basis for the equations by which these separation distances are calculated.

Reference 3 specifies a chamber interval of 1.5 $W^{1/3}$ (0.6 $Q^{1/3}$) "to prevent propagation of explosion resulting from high speed rock spall." (Ref 5) Armed Services Explosives Safety Board Technical Paper summarizes the results of explosive tests conducted in salt mines in Germany in 1936. Four tests were conducted in which detonable items were placed in chambers adjacent to the detonation chambers.

The closest range at which there was no communication as a result of chamber damage was 0.73 $W^{1/3}$ (0.29 $Q^{1/3}$). Contents of two chambers at ranges of 1.31 $W^{1/3}$ (0.52 $Q^{1/3}$) detonated when flames and hot gases entered through unprotected entrances. Under normal magazine conditions, these chambers would have had doors to exclude these effects. The closer separation distance thus is a more reasonable criterion, and is the approximate value recommended by the report.

The explosive charge densities used in these tests were 11.6 to 11.8 lb/ft^3 (185 to 189 kg/m^3), compared to the standard NATO charge density of 16.9 lb/ft^3 (270 kg/m^3). A curve of the adiabatic pressure-density relationship for TNT products given in the paper indicates that the pressure on chamber walls in the case of standard charge density would be approximately 1.86 times the value produced in the German tests. This could be the rational basis of requiring a safety factor of 2 on the noncommunication scaled distance determined from the tests.

Further justification for the separation distance to prevent communication can be found from the results of the Underground Explosive Test (UET) Program in rock (Ref 6). Table 1 shows the scaled distances from walls of the charge holes to the tunnel walls for limits of Zone 1 and Zone 2 damage. Both of these damage zones constitute complete closure of the tunnel. The summary shows that the noncommunication separation distance falls between the scaled limits of Zone 1 and Zone 2 damage. The value of 1.5 $W^{1/3}$ (0.6 $Q^{1/3}$) is reasonable despite the fact that the maximum range of Zone 2 damage was 2.63 $W^{1/3}$ (1.04 $Q^{1/3}$) because the UET rounds had charge densities between 15.5 and 76.4 lb/ft^3 (254 and 1,220 kg/m^3).

These experimental data lead to the following observations about the regulation specifying separation distances. There are large uncertainties in specified values. Experiments with relatively low charge weight to volume ratios in salt indicate safe distances of about half the specified values, but tests in sandstone with a wide range of charge weight to volume ratios indicate the safe distance could be nearly twice the specified value. It appears the factors other than charge weight should be considered in setting the noncommunication separation distance. Properties of the earth media and charge weight to volume ratios could be significant. Figure 1 is an example of the effect of charge density on limits of Zone 2 damage in UET sandstone. Although the data are poorly correlated, the trend is for larger safe distances with greater charge densities. More recent data (Ref 7) indicate that damage zone limits are also functions of media strength and scaled chamber size. Considering all factors, the noncommunicating separation distance of 1.5 $W^{1/3}$ (0.6 $Q^{1/3}$) could be considered accurate to ±50%.

The specific origin of separation distances to prevent damage was also difficult to isolate. Reference 3 refers to United Kingdom and United States studies and trials. The UET program is one of the most extensive U.S. programs that is applicable, so data from that effort were reviewed.

A reasonable criterion for selecting a safe distance at which damage could be avoided is to find the range at which little or no spalling occurs. This range can be calculated from UET data for sandstone and granite. From Table 1-4 of Reference 6, the following media properties were obtained:

Property	Sandstone	Granite
f_t, Tensile Strength, psi	240	640
E_t, Young's Modulus at Failure, psi	0.34×10^6	1.62×10^6

Equivalent data for limestone were not given. However, average compressive strength, Young's modulus in compression, and sonic velocity for UET limestone were all greater than equivalent values for granite. Modulus of rupture for the limestone was intermediate between values for sandstone and granite.

Using the data for granite and sandstone, the tensile strain at failure is estimated by the equation:

$$\varepsilon_f = \frac{f_t}{E_t} \tag{1}$$

Thus, for granite, ε_f = 395 µin./in., and for limestone, ε_f = 706 µin./in. Figure 3-1 of Reference 6 gives best fit curves and corresponding equations for peak free-field strain versus scaled distance in each of the test media:

$$\begin{aligned} \varepsilon &= 1.2 \times 10^4 \left(\frac{D}{W^{1/3}}\right)^{-2.0} \ \mu\text{in./in. for granite} \\ \varepsilon &= 1.9 \times 10^4 \left(\frac{D}{W^{1/3}}\right)^{-2.4} \ \mu\text{in./in. for sandstone} \end{aligned} \tag{2}$$

Assuming that the peak free-field compressive strain is reflected at the chamber wall as a tensile strain of equal magnitude, these equations can be used to solve for the scaled range for incipient spalling by substituting ε_f for ε. Carrying out those calculations gives the following ranges:

$$D = 5.5\ W^{1/3} \text{ for granite}$$

$$D = 3.9\ W^{1/3} \text{ for sandstone} \qquad (3)$$

Considering that the UET tunnels were unlined and that some of the shots were conducted with charge weight to chamber volume ratios significantly higher than is normally used for underground storage, safe separation distances of 3.5 $W^{1/3}$ for sandstone and 5 $W^{1/3}$ for granite are reasonable.

What may have occurred at this point is to assume that the safe distance for limestone would fall midway between sandstone and granite or 4.3 $W^{1/3}$ as is contained in present regulations. However, data from the UET report indicate that limestone might fall outside of that range. Average compressive strength was higher than granite, and the modulus of rupture, a measure of tensile strength, was only slightly less than the corresponding value for granite. The Young's modulus in compression was also significantly higher than for granite, but the rate at which peak strain attenuates is much greater in limestone than in the other media. Thus, the relative and absolute values for no damage in limestone are uncertain.

The UET data provide good verification for the damage-free separation distance in sandstone. The report divides tunnel damage into four categories or zones. Zones 1 and 2 consist of areas of very heavy damage with large amounts of rock being projected into the tunnel at high speed; Zone 3 consists of areas in which irregular spalling occurs; and Zone 4 consists of areas with some spalling and falling of already loose rocks. It seems reasonable that the maximum range of Zone 3 damage would be reasonable for the distance at which little or no damage to tunnel contents would occur. Table 2 shows the scaled range to the limit of Zone 3 damage on the sandstone shots. The scaled range indicated is the distance from the wall of the shot hole to the wall of the tunnel at the average limit of Zone 3 damage in each shot. Results appear to be independent of tunnel size and a value of 3.5 $W^{1/3}$ is exceeded in only a few cases. The average is 3.08 and the standard deviation is 0.63. Based on a normal distribution, the value of 3.5 would only be exceeded 25% of the time.

GROUND SHOCK

Inhabited building distance requirements for protection against ground shock are the same as those currently used by NATO (Ref 4). Allowable ground shock limits are given in terms of maximum particle velocities in various media. Ranges at which these velocity limits occur for the media are expressed in terms of a constant, a decoupling factor and the total charge weight. Various elements of the regulations will be discussed in the following order: allowable ground shock, inhabited building distance equation, and decoupling factor.

The NATO committee on explosives storage recommends that the criteria for the limiting ground shock environment be based on maximum particle velocity at the building site (Ref 8). The velocity limits were based on shock levels that would cause severe damage to residential type brick buildings. An article by Gustafsson and Hall was cited as the basis for these criteria (Ref 9). The same data are also contained in a book by Gustafsson published in English (Ref 10). Table 3 is derived from Gustafsson's book, in which he states that the velocity limits are based on more than 100,000 data points. The NATO code adopted the recommended velocity limit for buildings on sand, gravel, or moist clay directly from Gustafsson's data. Moraine, slate, and soft limestone were categorized as soft rock for code purposes and the velocity limit of 11.5 cm/sec was also adopted directly. Granite, gneiss, hard limestone, quartzite sandstone, diabase, and other media with seismic velocity between 4,500 and 6,000 m/sec were categorized as hard rock, and the committee evidently selected the rounded-off value of 23 cm/sec as the limiting velocity.

The concept of using peak velocity as a criterion for limiting ground shock-induced damage was confirmed by Nicholls, Johnson, and Duvall (Ref 11). Using data from numerous quarry blasts, they concluded that damage from ground shock correlates more closely with particle velocity than with acceleration or displacement. The report recommended a velocity limit of 2 in./sec (5 cm/sec) for all media. This value was selected as a lower bound value that would reduce the probability of damage to structures to less than 5%. This criterion was developed for use in mining and quarrying operations, and is significantly lower than what would be practical for explosive safety considerations. In the former case, the probability of an explosion is one, and, in fact, there will be many explosions at a given site. In the latter case, explosions are relatively rare, and a higher, though by no means catastrophic, level of damage is acceptable.

Reference 8 refers to two papers that provide equations for predicting velocities for establishing inhabited building distances. Hansen and Lombard in a 1965 paper (Ref 12) cite an equation given by Mickey in 1964 (Ref 13). The form of the equations and the exponents of the primary variables are identical:

$$V = K_V W^{2/3} R^{-3/2} \tag{4}$$

where V = velocity in cm/sec

K_V = constant dependent on the medium

W = explosive mass in tons (1 ton = 907 kg)

R = distance in km

The papers differ in the values given for K_V for tuff and granite. Respective values from each paper are as follows:

Item	Mickey	Hansen and Lombard
Alluvium	0.0144	0.0144
Tuff	0.036	0.359
Granite	0.0862	0.862

Solving Equation 4 for R and substituting the appropriate unit conversion factors gives

$$d = 48.5\left(\frac{K_V}{V}\right)^{2/3} Q^{4/9} \tag{5}$$

where d = range in metres

Q = charge mass in kg

Using the values of K_V from Hansen and Lombard and the allowable velocities for corresponding media gives the following equations for inhabited building distances.

$$\begin{aligned} d &= 0.9\ Q^{4/9} \text{ for sand gravel} \\ d &= 4.8\ Q^{4/9} \text{ for soft rock} \\ d &= 5.4\ Q^{4/9} \text{ for hard rock} \end{aligned} \tag{6}$$

With a value of 1.0 for f_s, these values are the same as the expressions for inhabited building distance in the NATO regulations. Using the values of K_V from Mickey's report gives the following:

$$\begin{aligned} d &= 0.9\ Q^{4/9} \text{ for sand, gravel} \\ d &= 1.0\ Q^{4/9} \text{ for soft rock} \\ d &= 1.2\ Q^{4/9} \text{ for hard rock} \end{aligned} \tag{7}$$

There is a strong basis for accepting the constants given in Mickey's original paper. Predicted velocities using his constants agree well with data presented, so the paper is internally consistent. Hansen and

Lombard do not present any velocity data, but simply quote Mickey's equations. It is quite possible, therefore, that the constants were incorrectly quoted. However, data from Project Hobo (Ref 14), which was also cited in Reference 8, show that the range at which a peak velocity of 11.5 cm/sec (4.5 in./sec) occurs in tuff correlates well with the expression for soft rock from Equations 6. Thus, there is a significant question as to whether the existing expressions for inhabited building distances (Equations 6) or those of Equations 7 are more appropriate. The difference is nearly a factor of 5.

The decoupling factor, f_g, is apparently based on data from a paper by Murphey (Ref 15). The paper reports results of 17 high explosive shots conducted at depths on the order of 800 feet (240 metres) in halite. Objectives of the tests were to develop methods for concealing underground explosions by using low explosive weight to volume ratios in charge holes. Charge weights varied from 20 to 2,000 pounds (9 to 900 kg); loading densities for untamped charges varied from 0.0018 to 0.26 lb/ft^3 (0.029 to 4.2 kg/m^3); peak velocities for all shots and all ranges were from 0.17 to 90 in./sec (0.43 to 230 cm/sec).

The decoupling factor can be defined as the ratio of peak velocity from a decoupled shot to the peak velocity at the same range for a fully tamped shot of the same size. This definition was used to calculate decoupling factors from Murphey's data; the plot of those values is shown in Figure 2. It should be noted that Murphey's definition of the decoupling factor is the inverse of the value defined here. It should also be noted that in Murphey's tests, the explosive used was Pelletol, which the paper describes as "TNT at 1 gm/cm^3" (62 lb/ft^3). Thus, the charge density at which the decoupling factor equals 1.0 corresponds to this value. Data from the paper and for a tamped charge are plotted in Figure 2. Neglecting the points for charge densities below 0.1 lb/ft^3 (15 kg/m^3), a line drawn through the points with charge densities in the usual range of interest approximates the equation

$$f = 0.14\left(\frac{W}{V}\right)^{1/2} \tag{8}$$

This expression for the decoupling factor should be inserted into the equation for velocity, thus

$$V = f\, K_V\, W^{2/3}\, R^{-3/2} \tag{9}$$

Solving this equation for R gives

$$R = (f)^{2/3}\left(\frac{K_V}{V}\right)^{2/3} W^{4/9} \tag{10}$$

Thus, the value of the decoupling factor f_g is

$$f_g = (f)^{2/3} = \left[0.14\left(\frac{W}{V}\right)^{1/2}\right]^{2/3} = 0.27\left(\frac{W}{V}\right)^{1/3} \tag{11}$$

Approximating this equation in terms of rational numbers gives

$$f_g = \frac{4}{15}\left(\frac{W}{V}\right)^{1/3} \tag{12}$$

This is the value used in calculating the decoupling factor for the U.S. regulations.

The decoupling factor appears to be an appropriate and necessary factor for evaluating ground shock effects from accidental explosions in underground storage chambers. However, the article cited as the basis for its derivation contains data which may not be appropriate for explosive storage conditions. Few data points were available in the range of charge densities that are common in explosive storage. The decoupling factor, in fact, appears to have very wide scatter for low charge densities, and this characteristic could cast doubt on the accuracy of the expression. A further criticism of the data is that it was obtained at a great depth of cover in a medium which may not be appropriate for explosives magazines. It may be possible that scaled depth of cover is an important parameter for ground shock prediction. However, the data does provide a baseline for a limiting case of a scaled depth parameter.

Despite the limitations and shortcomings of the decoupling factor, its significance should not be diminished. Coupling effects are significant from a theoretical and an intuitive point of view. The present form of the equation was based on the best available data, and little, if any, newer data are available. Before efforts are made to refine the present equations, the significance of the parameter for dictating critical ESQD arcs should be evaluated.

DEPTH OF COVER

Depth of cover considerations are significant for planning and evaluating underground explosives storage. Two specific depths are of significance for the explosives safety regulations: C_c, the depth required to insure containment and to eliminate significant disruption of the surface, and C_v, the depth at which air blast is not significantly suppressed at inhabited building distances. This section discusses the origins of the present values.

An early paper which addressed the problem of containment evaluated data from tamped nuclear detonations in tuff at the Nevada Test Site (Ref 16) and indicated the following average depths for the effects indicated. (Assuming a nominal conversion factor of 1 kt nuclear equals 1,000,000 pounds of TNT):

$$D = 2\ W^{1/3} \quad \text{no air blast at the surface}$$

$$D = 3.1\ W^{1/3} \quad \text{no crater} \qquad (13)$$

$$D = 4\ W^{1/3} \quad \text{no radiation escape}$$

These results indicate that a reasonably safe depth to provide containment for a chemical explosive would fall between 3.1 and 4.0 $W^{1/3}$.

The Armed Services Explosive Safety Board (Ref 5) concluded that complete containment requires a scaled depth of 5.0 $W^{1/3}$. This conclusion was based on the assumption of a fully tamped explosive charge that completely fills the chamber. It also states that a generally accepted camouflet depth (the minimum depth at which no surface crater forms) is 3.0 $W^{1/3}$ in soil. Therefore, depending on how one wishes to define containment, the approximate range of values of C_c could be widened to include 3.0 to 5.0 $W^{1/3}$.

The document that most closely defines the required depth for containment is a 1975 NATO informal working paper (Ref 17). It states that for planning and test design purposes the scaled minimum earth cover required to insure containment of a nuclear explosion in soil or soft rock is usually taken as 350 ft/kt$^{1/3}$ or 3.5 ft/lb$^{1/3}$ for nominal TNT equivalence. This is, in fact, the precise value used in the present regulations to define C_c.

Although the scaled depth for containment has been established by the regulations, the references cited indicated that a relatively wide range of values could be considered. They indicate a possible range of scaled depths from 3 to 5, and they do not provide a basis for considering the effects of different media. More recent discussions within NATO Committee AC/258 (Ref 18) are leading toward developing different containment depth criteria for different media. An initial proposal was to adopt expressions for containment depths in hard rock and soft rock which would be proportional to the charge weight to the 0.3 power (Ref 19): It was subsequently agreed to use depths scaled to the one-third power to be consistent with other criteria (Ref 20).

A second significant depth of cover is C_v, the minimum depth at which underground siting is effective in reducing shock and blast effects at inhabited building distances. Storage chambers where the depth of cover is less than this value must be treated the same as above-ground storage for establishing ESQD arcs. The present value of C_v is 0.5 $W^{1/3}$.

Small-scale tests by the Naval Ordnance Laboratory (Ref 21) showed that overpressures from detonations at scaled depths less than 0.5 $W^{1/3}$ were not significantly lower than for surface detonations. One-pound pentolite spheres were used and the reported scaled depths were measured from the charge centroid. Thus, scaled depths of 0.25 and 0.5 $W^{1/3}$ correspond to 0.19 and 0.35 $W^{1/3}$ measured from the chamber walls. These

factors and the fact that explosive charges completely filled the chamber indicate that the limiting scaled depth of 0.5 $W^{1/3}$ is a conservative value.

A further confirmation of the 0.5 $W^{1/3}$ value is from U.S. Army studies (Ref 22). Empirical curves derived from data on air blast from gas venting of buried explosions are used to predict the effects of burial depth. Data were from fully tamped TNT and nuclear detonations. No mention was made of how explosive energies were equated, but with the usual conversion of 1 kt nuclear equals 1,000,000 pounds TNT, Figure 3, which was derived from that report, shows a rational basis for selecting the minimum burial depth. The transmission factor is the ratio of overpressure for the buried blast to that for a surface burst at the same scaled ground range. Transmission factors greater than 1.0 may result from reflections or other complex phenomena. This curve shows that the transmission factor is 1.0 at a scaled depth of 0.5 $W^{1/3}$. Even with a more conservative conversion factor of 1 kt nuclear equals 1 kt TNT, the transmission factor equals 1.0 at 0.4 $W^{1/3}$, and the curvature appears to increase at a depth of 0.5 $W^{1/3}$. Data summarized in this report thus seem to verify the value selected as a minimum depth for underground siting benefits.

It is interesting to note that the depth of cover requirements are presently independent of the earth cover properties and independent of the structural properties of the chamber liner. Specified depths are slightly conservative but are not unrealistic. In the case of cover required for containment, the data indicate that the type of cover may be significant and that the value of 3.5 $W^{1/3}$ may be unnecessarily conservative for all media. In cases of shallow earth cover where the minimum depth controls, there may be cases where a relatively strong or massive chamber liner could provide partial containment to achieve the same reduction in blast effects as with earth cover. The effects of charge density in storage chambers could also be an important consideration that is not presently addressed in depth of cover regulations.

AIR BLAST

Air blast ESQD arcs for explosive storage facilities are simple constant radius arcs whose lengths are linear functions of the cube root of the total explosive weight. By contrast, the equivalent arcs for underground storage, where the depth of cover is less than the containment depth, are functions of the layout of the chambers and tunnels, and the length of the arcs vary as a series of step functions of the direction from the tunnel entrance. The forms and origins of these functions are discussed in this section.

The effects of chamber layout are calculated by the use of an effective or reduced charge weight, W_r, defined as:

$$W_r = \frac{W}{n\ k} \tag{14}$$

where W = total charge weight

n = 1 for a site with one entrance at the ground surface; 2 for a site with two or more entrances at the ground surface

k = 3 for explosives stored on a branch passageway of cross-sectional area not more than half that of the main passageway; 1 otherwise

The factor, n, considers the effect of energy partition from a possible detonation. A Norwegian report presents data that show that peak pressure at any point in a tunnel system is a function of the total charge weight to volume ratio up to the point of interest (Ref 23). Tunnel volumes are also considered as part of the total volume. Using this concept, however, would reduce the total effective charge weight by a factor of two only in the case of a chamber at the end of a tunnel with one entrance to the surface versus a chamber at the middle of a tunnel with surface access at both ends. However, the underlying principle demonstrated by this study is that peak blast pressure exiting from a tunnel system is a strong function of the total energy or charge weight density. Thus, on the average, effective charge weights based on blast pressures from two tunnel complexes with the same excavated volumes and actual charge weight detonated would differ by a factor of two if one complex had two entrances to the surface and the other had only one entrance. The factor $n = 2$ takes this difference into consideration for calculating external quantity distance arcs.

The factor, k, for calculating the reduced charge weight can be derived from data in Reference 24. The configuration of explosives stored in a branch passageway is analogous to a blast wave traveling up the stem of a "T" tunnel intersection. The report shows that data for the incident versus transmitted shock overpressure plots as a straight line on log-log axes. The slope is equal to 1.0 and, at higher overpressures such as would be experienced in a storage complex, the ratio of transmitted overpressure in the main passage to incident overpressure in the branch passageway is $P_t/P_i = 0.69$. Considering each of these pressures to be the result of some net explosive charge weight at a given scaled range, we can express that range as

$$P_t = R\, W_r^{1/3} \tag{15}$$

$$P_i = R\, W^{1/3} \tag{16}$$

where P_t = transmitted pressure for a detonation on a branch passageway

P_i = pressure for a detonation on the main passageway, i.e., no "T" junction present

R = constant for a given scaled distance

W = actual charge weight

W_r = reduced charge weight to account for "T" junction

Dividing Equation 15 by 16 gives

$$\frac{P_t}{P_i} = \left(\frac{W_r}{W}\right)^{1/3} \tag{18}$$

Substituting the value of P_t/P_i given previously and solving for W_r gives

$$W_r = (0.69)^3\ W = \frac{1}{3} W \tag{21}$$

Thus a value of k = 3 would account for the effective charge weight in the branch passageway configuration.

The added restriction of a reduced cross-sectional area for the branch passageway provides a measure of conservatism. Such a configuration would provide an expansion chamber effect for a shock wave emerging from the branch tunnel and further reduce the effective charge weight. A Norwegian informal working paper to NATO indicates that the effective charge weight reduction could be on the order of 50% for an area expansion of two to one (Ref 25).

The directional character of the air blast ESQD arcs for inhabited buildings is the same as the NATO counterpart in Reference 4.

Experimental data on which these distances were apparently based are reported in the Norwegian literature by Skjeltorp (Ref 26). The distances generally represent the isobars for 50-mbar (3/4-psi) overpressure. They are somewhat conservative relative to U.S. criteria for above-ground storage which permit overpressures to about 65 mbar (1 psi) (Ref 5). The model chambers reported by Skjeltorp were in a configuration in which n = 1 and k = 3 for estimating the effective charge weight; thus Q_r = Q/3. Scaled data from Skjeltorp's report are shown in Figure 4. Points are for the ranges and azimuths at which 50-mbar overpressures were measured. Superimposed on these points is the air blast ESQD arc pattern for inhabited buildings. Nearly all the data points fall on or within the arcs. These arcs appear to provide a safe envelope on the 50-mbar isobars for all events.

By contrast, Figure 5 shows the 65-mbar (1-psi) data plotted on the same arcs. The envelope appears to be unnecessarily conservative for this criterion. The degree of conservatism seems most pronounced in the area toward the front of the tunnel. Data points to the side and rear of the tunnel entrance fall within and reasonably close to the arcs. It may, therefore, be possible to reduce the length of air blast ESQD arcs in the 0-degree to 60-degree sector if the U.S. criterion for above-ground storage is adopted for underground storage sites.

DEBRIS HAZARD

The primary source of the debris hazard regulations for underground storage is an internal working paper by Dr. D. E. Jarrett of the British Ministry of Defence, (Ref 27). In this paper, Jarrett extrapolated data from the UET program conducted in the early 1950s at Dugway, Utah (Ref 6). He used data from the "dust" measurements which included observations of fallout and debris particles up to several inches in diameter. Jarrett's paper outlines the rationale for the regulation and develops specific equations.

The debris hazard regulation is one of the few explosive safety regulations for which a probability of injury is explicitly considered. In Reference 3 which predates the present regulations, the criterion is specified as one potential lethal debris strike in an area of 400 m^2 (4,000 ft^2). Jarrett assumes that in the event of an underground explosion, most exposed persons would be alerted to the event by the air blast or ground shock pulse and would have sufficient time to throw themselves flat on the ground in an attempt to avoid injury. Assuming that critical debris particles fall at an angle of 60 to 80 degrees to the horizontal, the human body in a prone position would present a vulnerable area of approximately 4 ft^2 (0.4 m^2) to such particles. Thus, one potentially lethal particle per 4,000 ft^2 would represent a probability of 1 in 1,000 of serious injury or death. This conditional probability criterion was then used to develop empirical equations to estimate safe distances for debris hazards.

The UET dust data were recorded in terms of mass density of debris per unit area at various ranges and in terms of specific ranges at which a given mass density was observed. Due to asymmetrics in the debris field, the total area covered by the debris was also reported. Jarrett used the average radius, r, at which a given debris concentration was found. Values of r versus $W^{1/3}$ were plotted for several different debris densities and for various scaled charge depths. Plotted in this manner, the lines of different debris area density were found to have the same slope regardless of medium or scaled depth of detonation. The distance from surface ground zero for a given debris environment could thus be expressed as:

$$r = K\, W^{0.41} \qquad (19)$$

where 0.41 is the value of the common slope.

Jarrett evaluated the probability of a lethal strike from various sizes of debris of various geologic media. He concluded that a strike from any discrete particle of 1/2-inch (1-cm) nominal diameter within the vulnerable area would be potentially lethal. UET data for the maximum range of discrete debris chunks of 1/2, 1, and 3 inches (1, 3, and 8 cm) nominal dimension are plotted on the graphs of debris as shown in Figure 6. A line through the data points for maximum range of 1/2-inch chunks falls slightly below and parallel to the line for 100 gm/m^2 debris

density. Jarrett thus suggests the use of the 100 gm/m^2 line for establishing safe debris distances. So for a given charge weight, medium, and depth of cover, a safe distance for debris hazard is established.

Clay was the primary geologic medium for which debris data were available for several depths of cover. The basic curves for safety distances as a function of earth cover were thus developed from test data in clay. This curve can be expressed in terms of Equation 19 where K is a function of the scaled depth of cover. Jarrett observed that the debris environment for clay with a scaled depth of cover of 0.51 $ft/lb^{1/3}$ (0.20 $m/kg^{1/3}$) was approximately equal to that for detonations in sandstone at a scaled depth of cover of 0.375 $ft/lb^{1/3}$ (0.15 $m/kg^{1/3}$). Further, the ratios of these depths to the scaled camouflet depth for each media were equal (0.51/4.2 = 0.121 for clay and 0.375/3.1 = 0.121 for sandstone). Jarrett thus concluded that the debris environment and consequently the safe distance for debris hazards is the same for various media when the ratio of depth of cover to camouflet depth is equal. Therefore, abscissas of the curves defining the earth cover function, K, are shifted based on the ratio of camouflet depth for the media relative to the camouflet depth for clay. The earth cover function, f_c, in Reference 1, is therefore the K function which has been adjusted to account for loading density. The values appear to be based on the envelope for the maximum range for 1/2-inch (1-cm) discrete chunks rather than on the lines for 100-gm/m^2 debris density.

The factor which accounts for effects of the explosive density within the underground chamber was based on two data points: UET tests and a British incident at Fauld. In the former, the charge density was 102 lb/ft^3 (1,630 kg/m^3) and in the latter, the density was 0.91 lb/ft^3 (14.5 kg/m^3). Jarrett found that scaling the UET debris data to the explosive weight which detonated at Fauld predicted the maximum debris range as 9,200 feet (2,800 metres) vice the measured distance of 4,200 feet (1,270 metres). He assumed that the difference was caused by the significant difference in loading density and assumed a logarithmic variation between the two data points. Using these two data points and normalizing the loading density factor based on the NATO normal density of 17 lb/ft^3 (270 kg/m^3) results in the equation:

$$f_d = (3.5)\, w^{0.18} \tag{20}$$

where w = charge density in lb/ft^3

Although the regulation was based on only two data points, Reference 3 shows data from an unspecified Norwegian trial falling very close to the line for loading density correction.

Thus, the debris hazard regulations can be traced directly to Jarrett's paper. Although the proposed regul. ions were based on a single series of tests and one accidental explosion, they are qualitatively consistent with above-ground storage criteria and theoretical analyses cited in the report. The primary way in which Jarrett's approach varies from current explosive safety practices is in the method of

specifying the depth of cover over the explosive. For underground storage calculations, the depth of cover is measured from the natural chamber ceiling to the natural ground surface, but the depth of cover from the UET tests was measured from the center of the explosive charge. Using the former definition would shift the curves for the earth cover function to the left so that peak values would fall at 0.64 $ft/lb^{1/3}$ (0.25 $m/kg^{1/3}$) for soft rock and 0.85 $ft/lb^{1/3}$ (0.34 $m/kg^{1/3}$) for hard rock. Except for relatively shallow depths of cover, this would have the effect of decreasing the safe distance; therefore, the current regulations are somewhat conservative.

Another interesting point with respect to the earth cover function is that the curve for hard rock is almost the same as the curve for clay or sand overburden. This occurs because the camouflet depth for granite is nearly equal to that for clay (4.0 versus 4.2). This implies that at sites at which the overburden is primarily soil, the curve for hard rock could be used to estimate safe debris hazard distances.

The preceding discussion of debris hazard radii was concerned with debris ejected from the earth cover over magazine chambers. A second source of debris hazard is the material projected out the tunnel entrance. This material could consist of ordnance and structural material fragments as well as earth materials. Present regulations specify a 2,000-foot (600-m) ESQD arc over a sector ±15 degrees off the axis of the tunnel. This phenomena was discussed in Reference 5. The primary conclusions were that maximum missile range is about 3,000 feet (900 metres) and this range is independent of total explosive weight. No specific test reports were cited.

One of the few reports that quantifies the phenomena is from Norway (Ref 28). Experiments consisted of ten detonations in a tunnel system; charge weights ranged from 220 pounds (100 kg) to 12,000 pounds (5,400 kg). All shots showed that debris from the tunnel entrance fell predominantly in the sector ±15 degrees on either side of the tunnel axis. This finding was probably the source of the regulations specifying the critical sector for debris from the tunnel. Figure 7 shows a plot of the maximum missile range versus cube root of the charge weight reported in the Norwegian tests. The data seem to indicate that the maximum missile range is a function of charge weight, rather than a constant. If this effect could be verified, the penalty suffered by relatively small explosive charges could be eliminated. Also shown in Figure 7 is a function that bounds the data and could be considered as an alternative to the present regulation if more data could be obtained to verify it. It should be emphasized that this function is a simplified hypothesis which was proposed by CEL as one possible alternative to present debris hazard criteria.

SUMMARY

This report represents the first effort in a study to evaluate the economic and operational feasibility of underground storage of explosives for the Navy. It provides a useful background and commentary on the

present underground storage regulations. A summary of the significant findings is as follows:

1. Chamber Separation Distance

a. The distance to prevent communication is slightly conservative, but the data scatter is large. The distance may be a function of media type and charge density.

b. Separation distances to prevent damage are uncertain, particularly for limestone. Distances appear to be functions of charge density.

2. Ground Shock Distances

a. Allowable ground shock levels appear to be reasonable.

b. An apparent error exists in the equations for safe distances in soft rock and hard rock. The error results in ESQD arcs that are conservative by a factor of nearly five.

c. A large uncertainty exists for the decoupling factor, f_g, at low charge densities.

3. Depth of Cover

a. The depth of cover for containment could range from 3.0 to 5.0, vice 3.5 $W^{1/3}$ in the regulation. This depth may also be a function of media type and charge density.

b. Provisions for minimum depth of cover appear adequate.

4. Air Blast

a. ESQD arcs in the sector 0 degrees to 60 degrees on either side of the tunnel centerline appear to be unnecessarily conservative.

b. Arc radii in other sectors appear to be adequate.

5. Debris Hazard

a. Although the equations were based on many data points, they were also broadly extrapolated. Thus, the degree of uncertainty in these equations is also highly uncertain.

b. ESQD arcs for debris hazard in the ±15-degree sector outside the tunnel entrance are unnecessarily conservative for small charges, and the radii should probably be a function of charge weight.

The next phase of this study will use the present regulations to estimate relative differences in initial costs for surface versus underground explosives storage. Various ratios of land cost to underground construction cost will be used to determine the sensitivity of the results to that variable. The analysis should also indicate which provisions of the underground storage regulations are most critical for determining land area encumbered by ESQD arcs. These results will help in identifying phenomenology areas in which additional research could lead to reduced radii for ESQD arcs. The data would also help to quantify the potential benefits of that research.

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Table 1. Damage Zone Ranges for UET Sandstone

Round	Scaled Range		Charge Density	
	$ft/lb^{1/3}$	$m/kg^{1/3}$	lb/ft^3	kg/m^3
Limits of Zone 1 Damage				
815	1.18	0.47	44.2	708
816	1.31	0.52	42.1	674
807	1.00	0.40	15.5	248
Zone 1 Average	1.16	0.46	33.9	543
Limits of Zone 2 Damage				
811	2.08	0.83	34.8	557
812	1.15	0.46	27.8	445
813	1.89	0.75	40.2	644
814	2.63	1.04	42.1	674
815	2.04	0.81	44.2	708
816	1.79	0.71	42.1	674
807	1.79	0.71	15.5	248
808	1.57	0.62	18.7	300
817	2.33	0.92	76.4	1,220
Zone 2 Average	1.92	0.76	38.0	608

Table 2. Range to the Limit of Zone 3 Damage in Sandstone

UET Shot	Tunnel Diameter (ft)	Range ($ft/lb^{1/3}$)
810	6	3.10
811	6	3.50
812	6	2.45
813	6	3.32
814	15	3.47
815	15	3.75
816	15	3.41
814A	6	3.55
807	6	2.49
808	6	1.66
817	30	3.62
817	6	2.69
Average		3.08
Standard Deviation		0.63

Table 3. Damage Suffered by Residential Units Subjected to Ground Shock

Peak Free-Field Velocities (cm/sec) and Associated Damage for--			
Sand, Gravel, Wet Clay (seismic velocity 1,000 - 1,500 m/sec)	Morainal Materials, Slate, Soft Limestone (seismic velocity 2,000 - 3,000 m/sec)	Granite, Gneiss, Hard Limestone, Quartzite, Sandstone, Diabase (seismic velocity 4,500 - 6,000 m/sec)	Damage
Peak Free-Field Velocities (cm/sec)			
1.8	3.5	7.0	No noticeable cracking
3.0	5.5	10.0	Fine cracks and some plaster falling
4.0	8.0	15.0	Cracking
6.0	11.5	22.5	Severe cracking

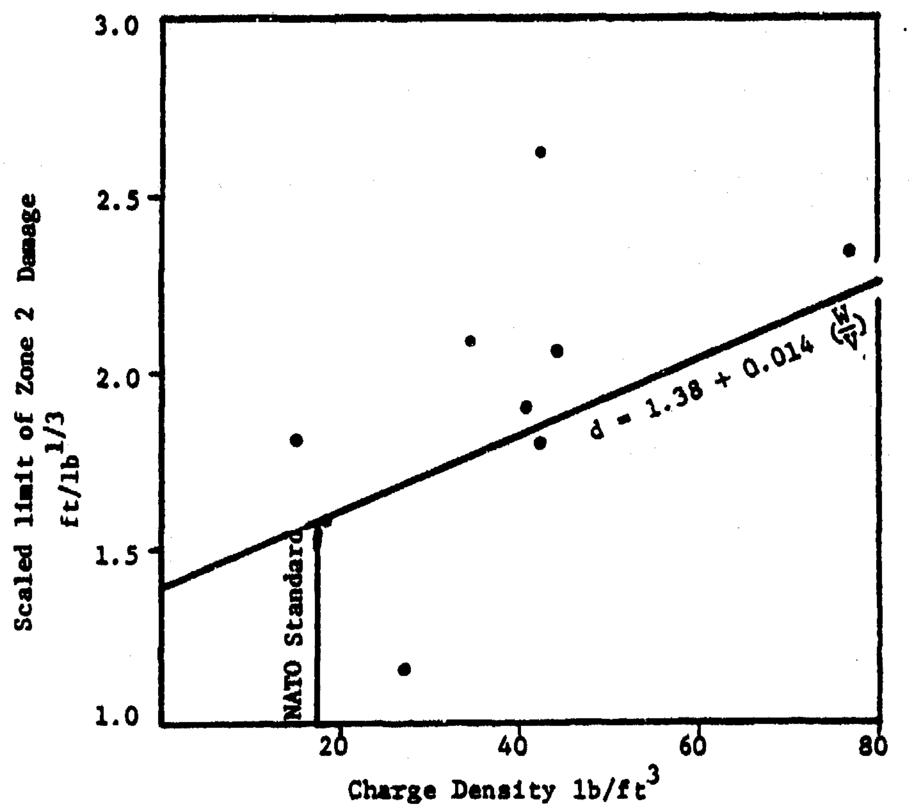

Figure 1. Damage ranges versus charge weight to volume ratio, UET sandstone.

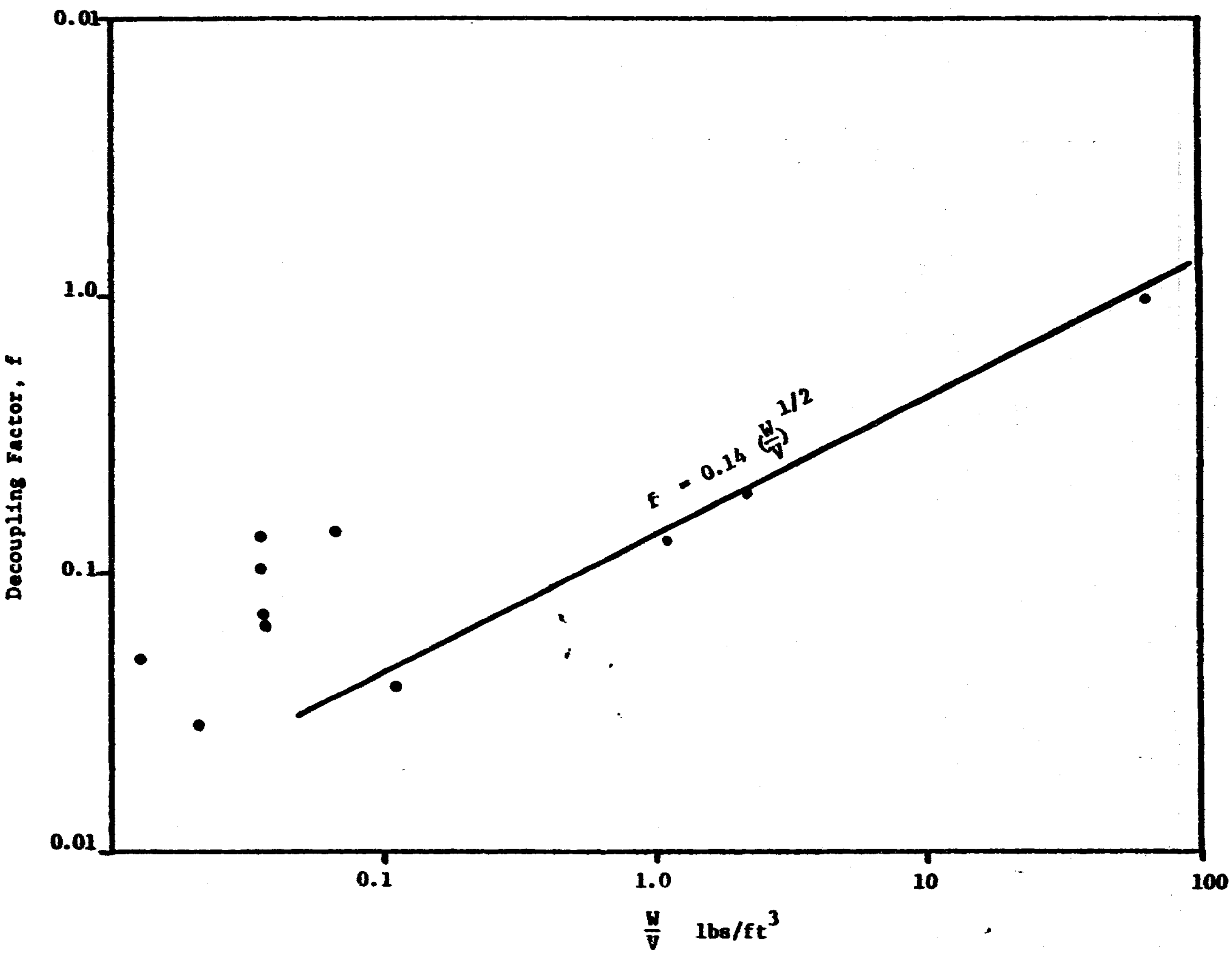

Figure 2. Experimental data from decoupling shots in halite.

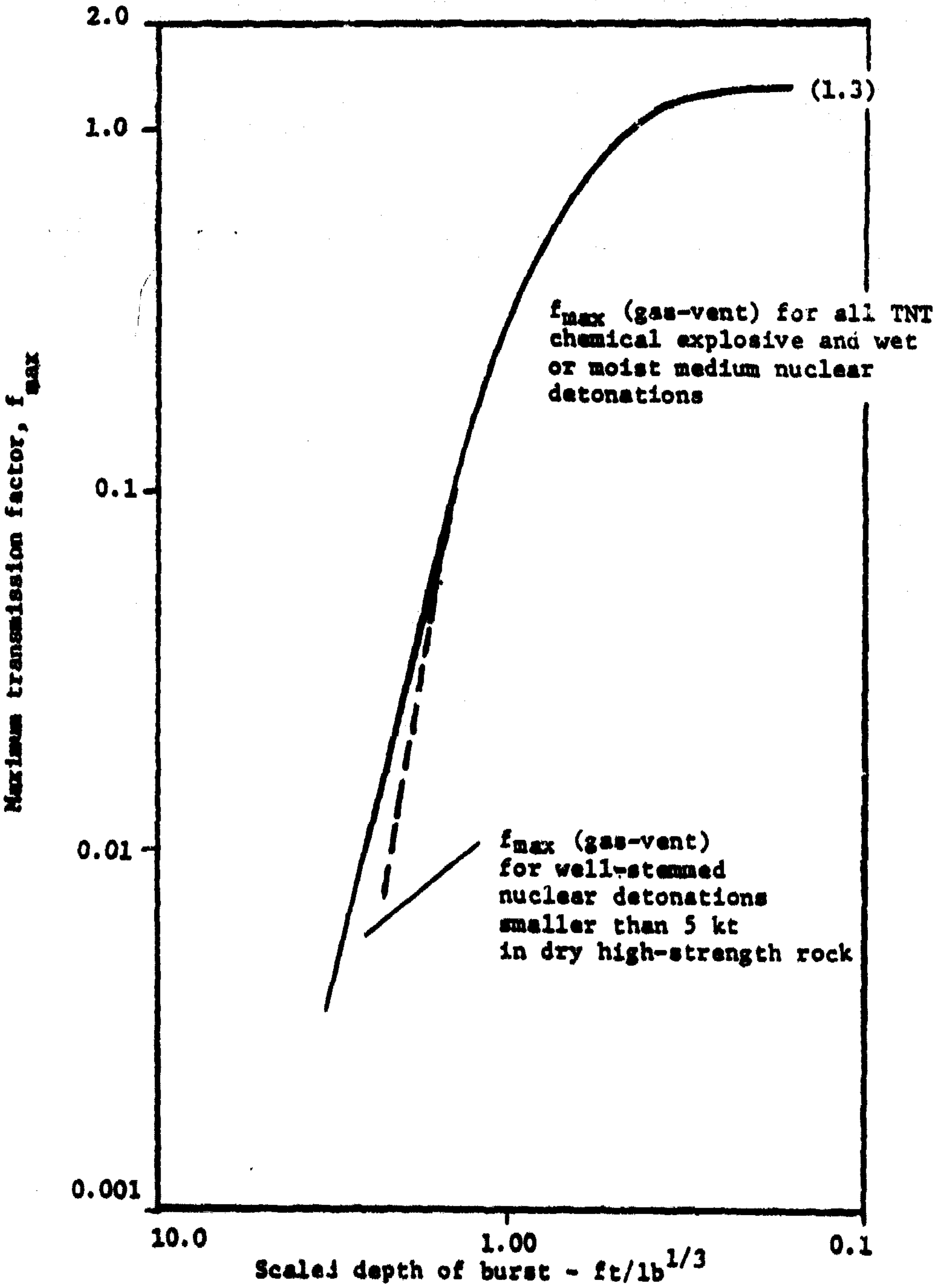

Figure 3. Maximum air blast transmission factor for single charge events.

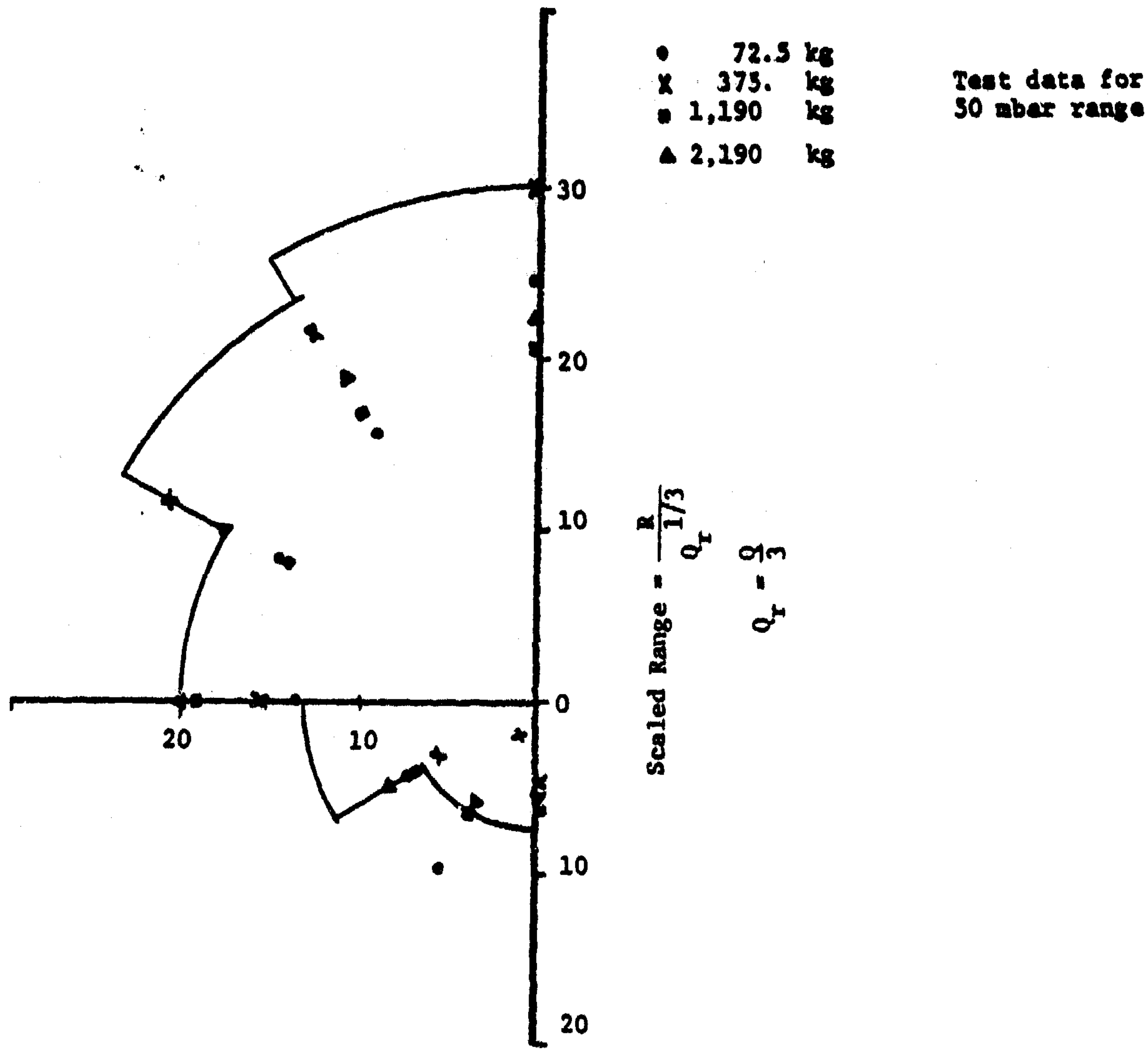

Figure 4. ESQD arcs and test data for 50 mbar (3/4 psi) overpressure.

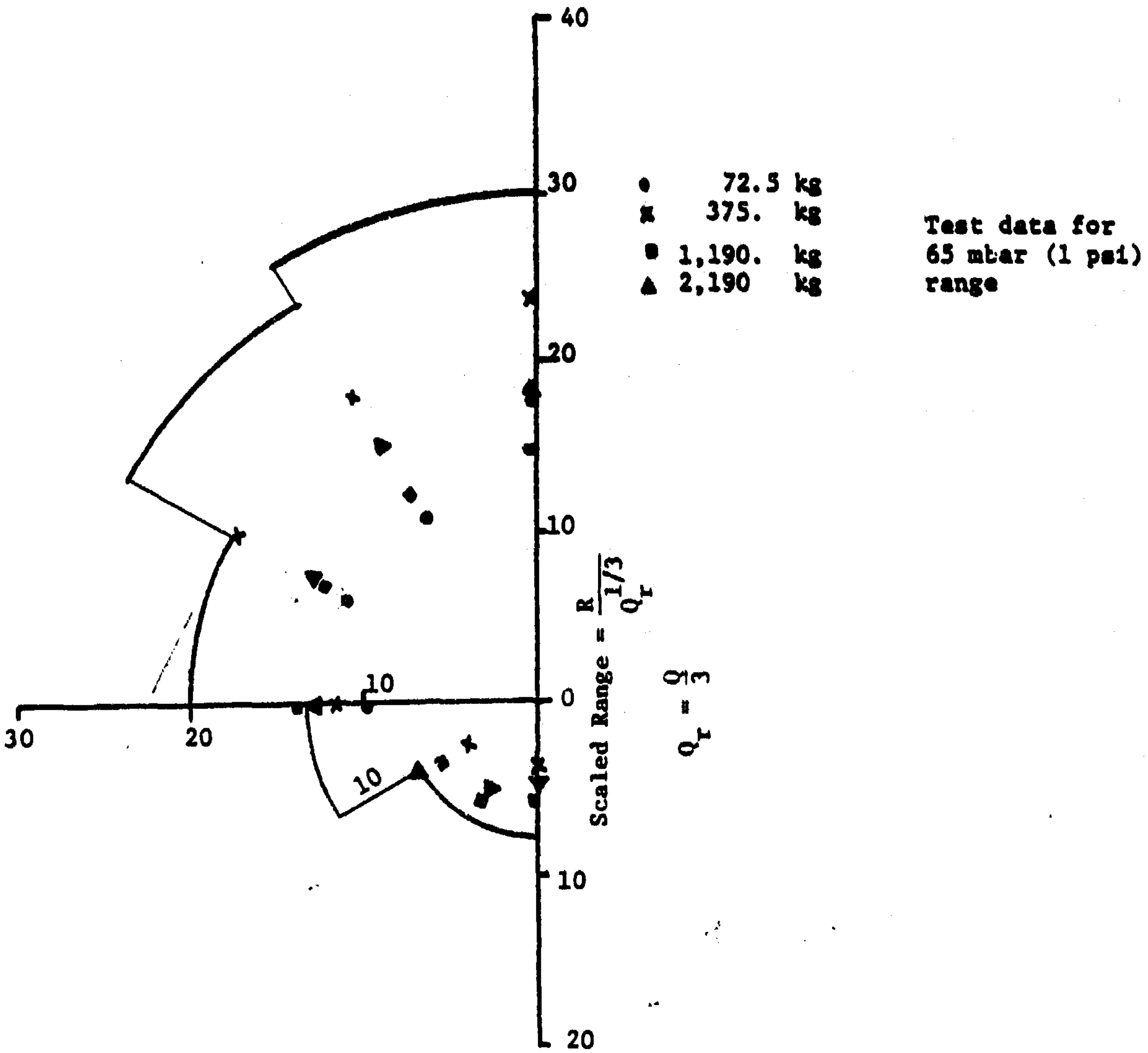

Figure 5. ESQD arcs and test data for 65 mbar (1 psi) overpressure.

Key - Lt. ½" chunks
Lt. 1" chunks
Lt. 3" or more

discrete debris

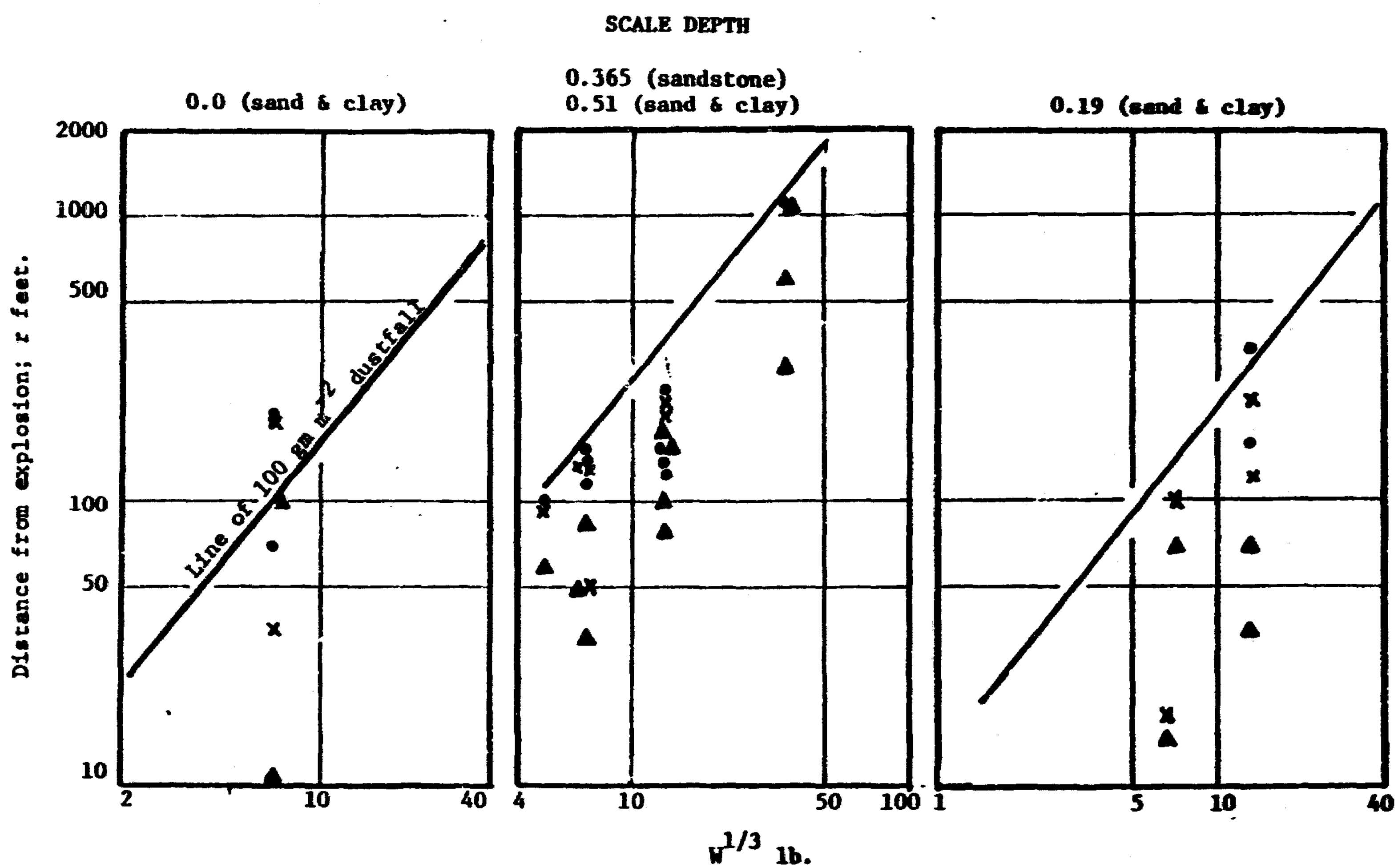

Figure 6. Debris and dust distribution data from Jarrett.

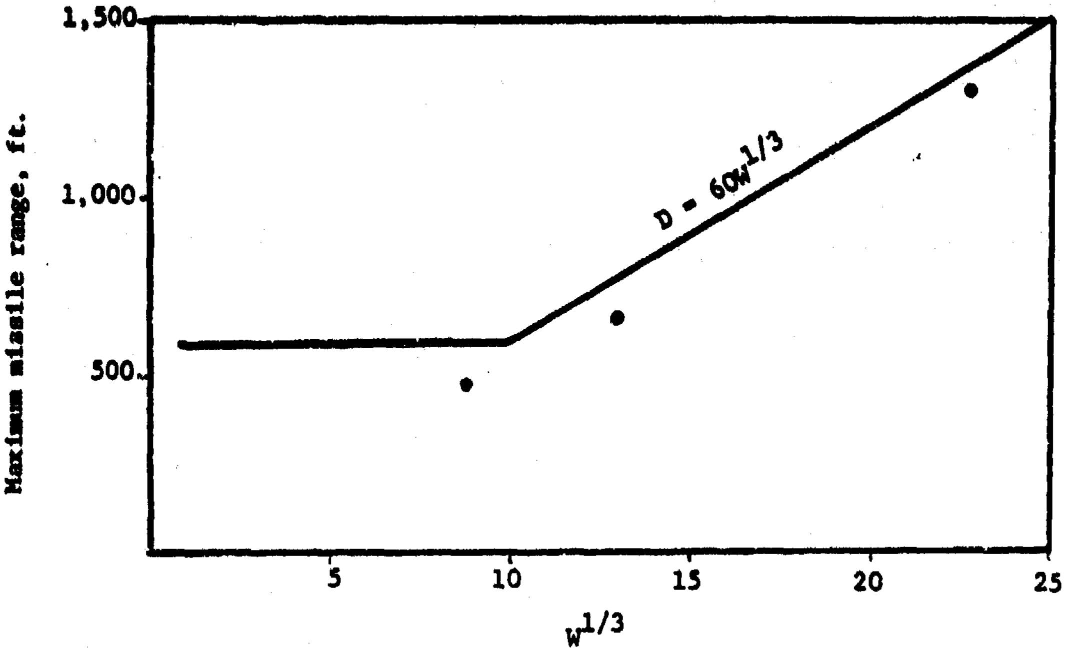

Figure 7. Maximum missile range for debris from tunnel entrances.

SCALING OF UNDERGROUND EXPLOSIONS

by

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ABSTRACT

Model tests are the usual method to investigate the effects of the blast wave originating from an explosion in an underground ammunition storage. The scaling laws used neglect several physical effects, such as effects due to viscosity. To examine the importance of these effects model tests in three different scales were performed. The scales are 1:100, 2:100 and 3:100 of a typical size. The results from the tests, which indicate a systematic deviation from the scaling laws, are presented and discussed. The possibility of using other methods to study the air blast from underground explosions is also discussed.

INTRODUCTION

Small scale model tests are commonly used to predict the air blast effects from accidental explosions in underground ammunition storages. The method requires that the model is geometrically similar to the storage under investigation, and the ratio between the amount of explosives in the storage and the model must be equal to the cube of the linear scale factor.

This simple scaling law is derived from dimensional analysis under the assumption that some physical effects can be neglected. For explosions in free air the scaling law is verified experimentally, but the validity of the necessary assumptions in the underground case is not sufficiently verified.

It is the objective of the model tests performed at NDRE to examine the validity of the simple scaling law for the air blast from an underground explosion.

DIMENSIONAL ANALYSIS

It is useful to perform a dimensional analysis to demonstrate what kind of assumptions which are necessary.

Fig. 1 represents simple models of an underground storage. From a steep mountain side a tunnel leads into the hall where the ammunition is stored. Let Q be the amount of explosives. We want to examine how the front pressure p varies with distance L from the hall, both in the tunnel and in the terrain outside the tunnel. The tunnel diameter is D. The properties of the ambient air may be described by its pressure p_o, sound velocity a_o and kinematic viscosity ν. The walls are described by their thickness d, their thermal diffusivity α and their elastic properties, the Young modulus E and the Poisson ratio σ.

Let us assume that the problem is sufficiently described by these 11 parameters, Q, p, L, D, p_o, a_o, ν, d, α, E, σ. 8 dimensionless parameters can then be formed:

$$\Pi_1 = \frac{p}{p_o} \qquad\qquad \Pi_3 = \frac{a_o{}^2 Q}{p_o D^3}$$

$$\Pi_2 = \frac{L}{\left(\frac{a^2 Q}{p_o}\right)^{1/3}} \qquad\qquad \Pi_4 = a_o \frac{D}{\nu}$$

$$\Pi_5 = \frac{d}{D} \qquad \Pi_7 = \frac{E}{P_o}$$

$$\Pi_6 = \sigma \qquad \Pi_8 = a_o \frac{d}{\alpha}$$

The front pressure p is determined by a relation of the form

$$(1) \quad \Pi_1 = f(\Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8)$$

All the Π-terms must remain unchanged if the results from experiments in a model shall be used to predict the results from full scale explosions. That is, we must be able to vary D, but still keep all the Π-terms fixed. Obviously that is not possible in this case.

Π_4 is proportional to D. Hence, if viscosity is important to the problem, it is impossible to scale from small models to full scale without taking the effects of viscosity into account. In a freeair explosion the viscosity can certainly be neglected, but in an underground explosion the blast wave propagation may be strongly influenced by the boundary layers at the tunnel walls. In this case viscosity can not be neglected, and there are strong indications that scaling is impossible just for this reason (1).

We also notice that Π_5 and Π_8 can not remain constant at the same time. If the heat lost to the walls is a significant part of the total energy, this will make scaling difficult. That will be true also in the case of very thich walls, since in the limit $d \rightarrow \infty$, Π_5 must be dropped, and d be replaced by D in Π_8. Π_8 will then be proportional to D. A simple estimate suggests that the heat loss to the walls is relatively important in small scales, but unimportant in large scales (2).

To obtain the standard scaling law it must be assumed that both Π_4 and Π_8 can be neglected. Relation (1) is then reduced to

$$(2) \quad \Pi_1 = f(\Pi_2, \Pi_3, \Pi_5, \Pi_6, \Pi_7)$$

The Π-terms involving the elastic properties of the walls do not lead to any problem for scaling. If the ratio between the wall thickness and tunnel diameter is constant, and the material in the walls is the same, Π_5, Π_6 and Π_7 will remain fixed. The amount of energy involved in elastic deformation of the walls is very small compared to the total explosion energy. For these reasons Π_5, Π_6 and Π_7 can be neglected. If plastic deformations should occur, however, these terms, in addition to Π-terms involving the plastic properties of the material, must be included.

If Π_5, Π_6 and Π_7 are neglected (2) reduces to

$$(3) \quad \Pi_1 = f(\Pi_2, \Pi_3)$$

or

$$(4) \quad P = \frac{p-p_o}{p} = f\left(\frac{L}{\left(\frac{a_o^2 Q}{p_o}\right)^{1/3}}, \frac{a^2 Q}{p_o D^3}\right)$$

This scaling law is the basis for performing model tests. When the linear dimensions are changed with a factor k and the amount of explosives is changed with a factor k^3 equal results should be obtained. We shall call this scaling with respect to dimension. As we have seen this principle is based upon the assumptions that viscosity and heat conduction can be neglected.

It is an experimental fact that a plane shock wave is formed in the tunnel at some distance from the explosive charge. It may be reasonable to assume that this plane shock wave is equivalent to a shock wave resulting from the explosion of a cylindrical charge filling the cross section of the tunnel. In that case the mass of the charge is proportional to its length, and the scaling law can be simplified to the final form

$$(5) \quad P = f(L_s)$$

where

$$(6) \quad L_s = \frac{LD^2}{Q}$$

is scaled distance, and where p_o and a_o are assumed to be constant. This relation is assumed to be valid in the tunnel at some distance from the charge. It states that the ratio between the distances from the charge where a certain pressure occurs is equal to the ratio between the charge weights. It is valid for experiments performed in the same model scale, that is, with the same value of D. We shall call it the principle of self-similarity.

The scaling law (5) thus contains two principles; scaling with respect to dimension and self-similarity.

Since the scaling law in the forms (4) and (5) are based on some unverified assumptions, NDRE started model tests with geometrically similar models in three scales to examine the validity of the law.

DESCRIPTION OF THE MODELS

The models consist of two parts. One is the tube which simulates the underground tunnel. The other is the platform section consisting of a vertical steel plate above the tube outlet and a horizontal platform, simulating a steep mountain side and a flat terrain, respectively.

The tubes are designed to provide two different model configurations.

The first configuration (CFG.1) consists in principle of a straight tube with a detonation section in the middle as shown in Fig. 1 a.

The second configuration (CFG.2) in principle consists of a straight tube connected to a detonation chamber in the one end. The other end leads to the platform as shown in Fig. 1 b. The cross section area of the detonation chamber is twice the cross section area of the tube.

The tunnel diameters in both configurations are 0.05 m, 0.10 m and 0.15 m respectively for the scales 1:100, 2:100 and 3:100.

The models were made to allow for the mounting of pressure transducers along the tubes, one for each four diameter length. Pressure transducers were also mounted on the platform along the projection of the extended tube axis with one per each 0.5 m approximately. The transducers on the platform, however, did not work sufficiently well, so the analysis of the blast wave propagation on the platform had to be based on the measurements of the time of arrival of the blast wave.

The transducers used in the tube were of three different types, all manufactured by Kistler Instruments AG, namely type 7005 with a resonant frequency 80 kHz, type 601 A with resonant frequency 130 kHz and type 701 H with resonant frequency 65 kHz. The charge amplifiers were designed and built at NDRE. The data from the measurements in the tube were recorded on a 14 channel SANGAMO instrumentation recorder type 3500, and the data from the platform measurements were recorded on a 14 channel EMI instrumentation recorder type SE 5000. The tape speeds of the recorders were 60 in/s, and at this speed their bandwidth is 20 kHz.

Since the positive duration of the blast wave in the tube is of the order of several milliseconds we believe that a sufficiently good registration of the front pressures is obtained.

Both model configurations allow for a large scale roughness in the tubes to take three different values, $r_L = 0$, $r_L = 0.03$ and $r_L = 0.06$. The large scale roughness r_L is defined by the relation

$$(7) \quad r_L = \frac{\Delta D}{D}$$

D is tube diameter and $2\Delta D$ is the height of the roughness elements as shown in Fig. 2.

The charges are pressed TNT charges. They are of cylindrical shape and for both configurations the diameters are the same fraction of the tube diameter in the three scales. This fraction is 0.38 for CFG.1 and 0.29 for CFG.2.

The wall thickness does not scale exactly, however. Since the energy involved in elastic deformation of the walls is small, and since no plastic deformation was observed, this is believed to be of little importance.

EXPERIMENTAL SERIES

The main series of experiments consisted of approximately three shots in each of six charge groups in the three scales and for the three values of wall roughness and the two configurations. With charge group we mean

$$(8) \quad q = \frac{Q}{D^3}$$

where Q is the chage weight. The charge groups and the corresponding charge weights in the three different scales are listed in Table 1.

The shots with the largest charges in scale 3:100, CFG.2, were for different reasons only performed in the case of $r_L = 0$.

MEASUREMENTS IN THE TUBE

Our analysis of the data from the tube is based on the recorded front pressures and time of arrival of the blast wave. From the recorded arrival times we calculate the time needed for the shock front to propagate a distance of 8 tube diameters in the tube. That is, we associate with a position L in the tube a time difference T(L) defined by

$$(9) \quad T(L) = t(L + 4D) - t(L - 4D)$$

where t(L + 4D) and t(L - 4D) are the arrival times at positions L + 4D and L - 4D respectively. T(L) is the resiprocal value of an average shock velocity between positions L - 4D and L + 4D. If the scaling law (5) is correct, then the scaled time difference

$$(10) \quad T_s = \frac{T}{D} \cdot a_{rel}$$

must satisfy the relation

$$(11) \quad T_s = g\ (L_s)$$

a_{rel} is the ratio between the sound velocity at the actual temperature in the air ahead of the shock front and the sound velocity at 0°C.

To be sure that we only examine a region of the tube where an approximately one-dimensional shock wave is formed we have included only positions $L \geq 16D$ in the analysis.

LINEAR REGRESSION

We shall examine the possibility of a deviation from the scaling laws

$$(5) \quad P = f(L_s)$$

$$(11) \quad T_s = g(L_s)$$

and we let the deviation be a linear expression in D, q and $(\frac{L}{D})$. That is, we assume that

$$(12) \quad P = f(L_s) + \alpha_1 D + \{\alpha_2 + \alpha_3 (L_s - L_{s0})\} q$$

$$= f(L_s) + \alpha_1 D + \alpha_2 q + \alpha_3 (\frac{L}{D} - L_{s0}\, q)$$

and

$$(13) \quad T_s = g(L_s) + \alpha_1' D + \{\alpha_2' + \alpha_3' (L_s - L_{s0})\} q$$

$$= g(L_s) + \alpha_1' D + \alpha_2' q + \alpha_3' (\frac{L}{D} - L_{s0}\, q)$$

The α-parameters are determined by the method of least squares. α_1 and α_1' measure the deviation from scaling with respect to dimension, while $\{\alpha_2+\alpha_3(L_s-L_{s0})\}$ and $\{\alpha_2'+\alpha_3'(L_s-L_{s0}\}$ measure the deviation from self-similarity. α_2 measures the deviation from self-similarity which is established for a small value of L_s, L_{s0} and α_3 measures how the deviation depends on L_s. L_s varies between 0.025 m^3/kg and 0.600 m^3/kg in our tests. The smallest values of L_s result from the same charge group (q = 640, n = 16 and n = 20). It is only meaningful to study the deviation from self-similarity over a range of L_s-values obtained by different charge groups. Hence, we choose L_{s0} = 0.0375.

The linear forms (12) and (13) do of course not necessarily represent the best fit to the deviation, but a possible non-zero deviation can be revealed. The scaling laws will be rejected if the deviation from zero of the α-parameters is statistically significant. This is assessed by the Students T-test.

We shall test the following null-hypotheses:

$$H_o : \alpha_1 = 0 \qquad H_o : \alpha_2 = 0 \qquad H_o : \alpha_3 = 0$$

$$H_o : \alpha_1' = 0 \qquad H_o : \alpha_2' = 0 \qquad H_o : \alpha_3' = 0$$

The test level is ε, i.e. the probability that the hypothesis is correct although it must be rejected by the test criterion, shall be less than ε. The test criterion is that H_o is rejected if $T > c$, where T is the Students T-statistic for the actual α-parameter, and c is the $(1 - \frac{\varepsilon}{2})$-fractil for the Student distribution with N degrees of freedom. N can in this connection be set equal to infinity.

The values of c for some values of test level ε are listed in Table 2.

The resulting ε-values and the corresponding T-values are listed in Table 3.

DEVIATION FROM SCALING WITH RESPECT TO DIMENSION

We see that α_1 is positive and $T > c$ at the test level $\varepsilon = 0.2\%$ for all values of r_L in both configurations. We have thus found that the recorded front pressure increases significantly with increasing scale.

We also see that α'_1 is negative in all cases. This shows that the scaled time difference decreases with increasing scale, corresponding to an increase in shock velocity and front pressure. For zero wall roughness the nullhypothesis must be denied at the test level $\varepsilon = 0.2\%$ in both configurations. In two cases is the significance weak, namely when $r_L = 0.03$ in CFG.1 and when $r_L = 0.06$ in CFG.2. In the former case the hypothesis $H_o : \alpha'_1 = 0$ must be denied at a test level $\varepsilon = 40\%$ and in the latter case at a level $\varepsilon = 20\%$. In the two remaining cases, $r_L = 0.06$ in CFG.1 and $r_L = 0.03$ in CFG.2, the null-hypothesis must be rejected at levels 1% and 0.2%, respectively.

From these results it must be concluded that the scaling laws (5) and (11) are not satisfied in our tests. The front pressure increases with increasing scale.

DEVIATION FROM SELF-SIMILARITY

The values of α_2 and α_3 are both negative in all cases. At a level $\varepsilon = 0.2\%$ H_0 : $\alpha_2 = 0$ must be rejected in all cases. The situation is not so clear for α_3, but when the values of r are compared with the values of c in Table 2 it is reasonable to reject the hypothesis $H_0 : \alpha_3 = 0$. In every case $\{\alpha_2 + \alpha_3(L_s - L_{s0})\}$ is negative, and the deviation ΔP from self-similarity

$$\Delta P = q\{\alpha_2 + \alpha_3(L_s - L_{s0})\}$$

is negative. $|\alpha_2 + \alpha_3(L_s - L_0)|$ seems to increase with inceasing scaled distance, L_s.

The values of α_2' and α_3' are in all cases positive. The values of α_3' are also in all cases significantly different from zero at a test level $\varepsilon = 0.2\%$. Except for case $r_L = 0.03$ in CFG.1 α_2 is significantly different from zero at a test level $\varepsilon = 1\%$. Hence, the arrival time measurements also indicate that there is a deviation from self-similarity. The deviation from self-similarity

$$\Delta T_s = q\{\alpha_2' + \alpha_3'(L_s - L_{s0})\}$$

is positive, corresponding to a negative value of ΔP.

Thus, if a certain pressure is obtained at position n = n, after detonation of a charge of weight Q = Q, a smaller pressure will be obtained at position n = kn, after detonation of a charge of weight Q = kQ, (k > 1). According to the principle of self-similarity these pressures should be equal.

DESCRIPTION OF THE BLAST WAVE PROPAGATION INSIDE THE TUBE

In the preceeding sections no assumptions were made about the functional form of the dependence of front pressure on distance. In order to examine the blast wave propagation inside the tube a power curve of the form

$$(14) \quad P = P_0 \left(\frac{L}{16D}\right)^{-C}$$

is fitted to the front pressures. P_0 represents the front pressure relatively close to the charge, at position L = 16D, and C represents the attenuation of the front pressure. When this power curve is applied separately for each tube diameter D and each charge group q, we obtain good correlation, but we find that P_0 and C depend on D and q.

Since we want to examine the dependence of P_0 and C on D and q, the expression

$$(15)\quad \ln P = \{\beta_1 + \beta_2 \ln (\frac{D}{0.05}) + \beta_3 \ln (\frac{q}{80})\}$$

$$-\{\beta_4 + \beta_5 \ln (\frac{D}{0.05}) + \beta_6 \ln (\frac{q}{80})\} \ln (\frac{L}{16D})$$

is fitted to the recorded front pressures by the method of least squares. It is performed separately for each value of roughness in both configurations. The resulting β-values and the corresponding values of Student's T-statistic are listed in Table 4.

Eq. (15) is equivalent to eq. (14) with

$$(16)\quad P_0 = e^{\beta_1} (\frac{D}{0.05})^{\beta_2} (\frac{q}{80})^{\beta_3}$$

$$(17)\quad C = \beta_4 + \beta_5 \ln (\frac{D}{0.05}) + \beta_6 \ln (\frac{q}{80})$$

If the scaling law were valid, and if the power curve describes the relation between front pressure and distance fairly well over the whole range of L_s-values included in the tests, we should obtain $\beta_2 = \beta_5 = \beta_6 = 0$ and $\beta_3 = \beta_4$.

In Figures 3a-f the results from det curve fitting are used to plot front pressure versus scaled distance for q = 640 kg/m^3 in scales 1:100 (D = 0.05 m) and scale 3:100 (D = 0.15 m).

It is of interest to decide wheter the deviation from scaling with respect to dimension is established immediately after the explosion, or if it is due to a scale dependent damping of the shock as the blast wave propagates through the tube. Since β_5 is negative in all cases except one (r_L = 0 in CFG.2), the scale dependence seems to increase as ths shock wave propagates through the tube. That is, the scale dependence seems to be due to a scale dependent attenuation. This effect is greater the greater the wall roughness.

Figures 4a-f show how the front pressure varies with scaled distance in scale 1:100. For a given value of scaled distance the front pressure decreases with increasing charge group, but this effect seems to be smaller the larger the scaled distance. The deviation from self-similarity increases with increasing value of wall roughness.

It is also clear from Figs 4 that the front pressure decreases faster than a power law in L_s. Over a limited range of L_s-values the power law is a good approximation, but it cannot be used to describe

the pressure-distance relationship over a large range of L_s-values.

We have used several curveforms which are more complicated than (15), but the qualitative results remain the same.

BLAST WAVE PROPAGATION OUTSIDE THE TUNNEL

The appropriate form of the scaling law outside the tunnel is eq. (4), where L now denotes the distance from the tunnel outlet. Since the analysis of the shock propagation on the platform must be based on the recorded time of arrival, t, of the shock, it is convenient to replace P with $\frac{L-a_0t}{L}$ in (4). The scaling law then takes the form

$$(18) \quad \frac{L-a_0t}{L} = f\left(l_s \; , \; \frac{a_o{}^2q}{p_0}\right)$$

where

$$(19) \quad l_s = \frac{L}{\left(\frac{a_o{}^2q}{p_0}\right)^{1/3}}$$

is a dimensionless, scaled distance.

A curve fitting procedure is performed in order to study the shock propagation on the platform. The relation between corresponding values of L and t is found to be fairly well described by

$$(20) \quad \frac{L-a_0t}{L} = K \left(\frac{l_s}{7}\right)^{-B}$$

for $l_s > 7$. In the region closer the tube outlet the shock propagation changes from one-dimensional to three-dimensional. Figs 5a-b.

According to (18) we must expect K and B to depend on $\left(\frac{a_o{}^2q}{p_0}\right)$. They may also depend on other Π-terms which were neglected in developing (4). Since the energy loss in the tube depends on the kinematic viscosity ν and the thermal difussitivity α of the tube walls, the total energy of the blast wave when it enters the platform depends on these quantities. Consequently, the propagation of the blast wave on the platform may depend on ν and α.

By differentiating (20) with respect to t we obtain

$$(21) \quad \frac{M-1}{M} = (1-B)K \left\{\frac{l_s}{7}\right\}^{-B}$$

M is the Mach number of the shock front. $\frac{M-1}{M}$ is a direct measure of the strength of the shock, and for the small shock strengths at the platform, according to the Rankine-Hugoniot equation

$$(22) \quad \frac{M-1}{M} \approx M - 1 \approx \frac{3}{7} P$$

$(1-B)K$ represents the shock strength at a position relatively close to the tube outlet, $l_s = 7$, and B represents the attenuation of the shock.

Eq. (20) is fitted to the recorded arrival times for each shot separately. In order to study how the shock strength at the platform varies with D and q simple curve forms are fitted to the resulting values of B and $(1-B)K$.

The curve

$$(23) \quad B = \beta_1 + \beta_2 \ \ln \left(\frac{D}{0.05}\right)$$

is fitted to the B-values from all the shots in all charge groups for each roughness and configuration separately. The results are listed in Table 5. In the same way the curve

$$(24) \quad (1-B)K = \beta_1 \left(\frac{D}{0.05}\right)^{\beta_2}$$

is fitted to the values of $(1-B)K$. These results are listed in Table 6.

From Table 6 it is seen that the front pressure at the scaled distance $l_s = 7$ increases with increasing scale. The scale dependence is greater when tubes with rough walls are used. These effects were to be expected since they were also observed inside the tubes. From table 5 we see that the attenuation of the shock decreases with increasing scale, and the effect seems to be greater in the cases with large wall roughness. The scale dependence increases as the blast wave propagates along the platform, and the increase is greater the greater the wall roughness in the tube. These effects are illustrated in Figs. 6a-b.

The curves

$$(25) \quad B = \beta_1 + \beta_2 \ \ln \left(\frac{q}{80}\right)$$

and

$$(26) \quad (1-B)K = \beta_1 \left(\frac{q}{80}\right)^{\beta_2}$$

are fitted to the values of B and (1-B)K for all the shots in the three scales. It is performed separately for each value of roughness in both configurations. The results are listed in Tables 7 and 8.

We see from Table 8 that the shock strength at the scaled position l_s = 7 increases with increasing charge group. The dependence of B on q is only significant in the cases with zero wall roughness, and in these cases B decreases with increasing q. Figs 7.

The mean values of B and (1-B)K for each value of wall roughness, r_L are listed in Table 9. We observe that the shock strength at l_s = 7 decreases with increasing value of r_L, but also that the attenuation of the shock decreases with increasing r_L. The differences in shock strength created by the different values of wall roughness in the tube seems to decrease as the shock propagates away from the tube outlet. Fig. 8.

From eq. (21) and (22) the scaled distance l_{50} at which the front pressure has fallen to 50 mbar, can be calculated. It is calculated separately for each shot, and the curves

$$(27) \quad l_{50} = \beta_1 \left(\frac{D}{0.05}\right)^{\beta_2}$$

and

$$(28) \quad l_{50} = \beta_1 \left(\frac{q}{80}\right)^{\beta_2}$$

are then fitted to the resulting values of l_{50}. See Tables 10 and 11. The 50 mbar limit measured in meters, is related to the scaled 50 mbar limit l_{50} by the formula

$$(29) \quad \left(\frac{a^2{}_0 q}{P_0}\right)^{1/3} D$$

We observe that the 50 mbar limit increases with increasing scale, and that the effect is larger in the cases with large wall roughness.

We also observe that the 50 mbar limit increases faster with charge than a $\frac{1}{3}$ power law. It increases faster with q in the cases where r_L = 0 than when $r_L > 0$. It also increases faster in CFG.2 than in CFG.1.

CONCLUSIONS

It is clear from the preceeding sections that the front pressure alone does not give a sufficiently good description of the blast wave. The energy or impulse should also be taken into account. Although we have not yet analyzed our impulse data some conclusions follow from the analysis of the front pressure.

For increasing value of wall roughness we observed that the attenuation of the shock increases inside and decreases outside the tube. The front pressure at the end of the tube is reduced considerably by a large wall roughness. The energy, however, is not reduced by a correspondingly great amount since the attenuation outside the tube decreases with increasing wall roughness. The main result of the roughness is a decrease in front pressure and an increase in positive duration of the blast wave. When the blast wave leaves the tube most of its energy seems to be present, and the effect of the roughness decreases gradually. However, at such distances as the 50 mbar limit a dependence on wall roughness is still found in our tests.

We also observed that the attenuation of the shock increases with decreasing scale both inside and outside the tube. The effect of a small tube diameter seems to be more than just to make the pressure-time profile of the blast wave flatter. A greater part of the energy must have been lost in the small scales than in the large ones. The scale dependent energy loss may result from viscous friction at the tube walls and heat conduction through the walls. These effects will be large in very small scales, but can probably be neglected in very large scales. For this reason great care should be taken when results from model tests are used to predict results in a full scale test.

The question arises then whether numerical methods can be used to investigate underground explosions.

It is difficult to give a mathematical description of the blast wave propagation inside a tunnel. The basic equations of hydrodynamics must then be solved without neglecting heat conduction and viscous friction and with very complicated initial and boundary conditions.

However, it is probably not necessary to calculate the shock propagation in the tunnel. It is possible, and seems to be sufficient, to study numerically the blast wave propagation outside the tunnel. This problem has nearly cylindrical symmetry and can be treated as two-dimensional. Both the method of characteristics and finite difference codes can then be used, and viscosity and heat conduction can be neglected.

The front pressure and the total energy of the blast wave in the tunnel outlet should be taken as input parameters. It is not necessary to determine the front pressure in the tube outlet with great accuracy, since the energy seems to be the most important parameter. A conservative estimate of the total energy of the blast wave in the tunnel outlet is to put it equal to the energy content of the explosives.

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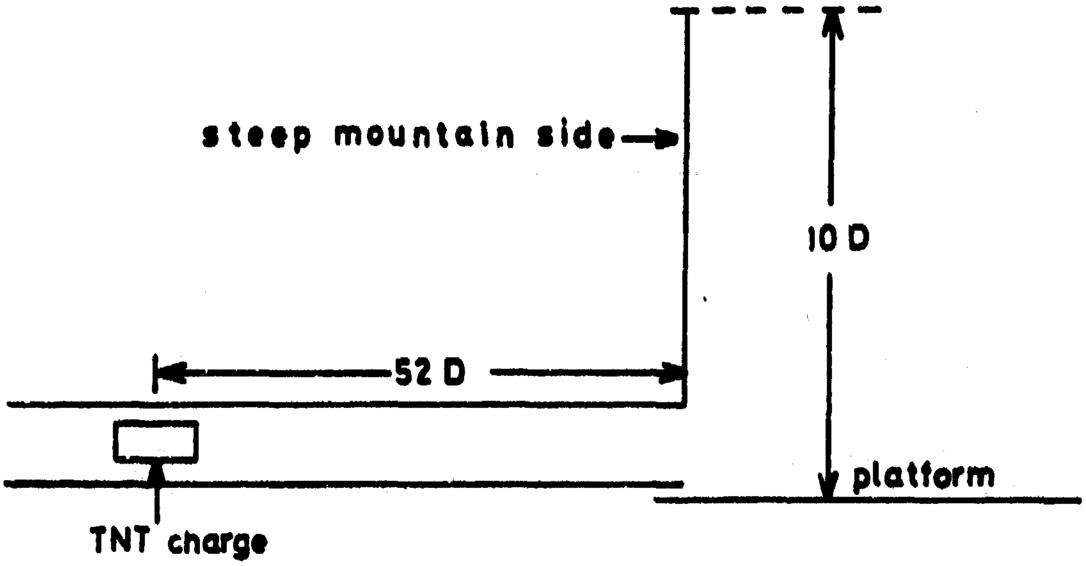


Figure 1a CFG 1 in principle

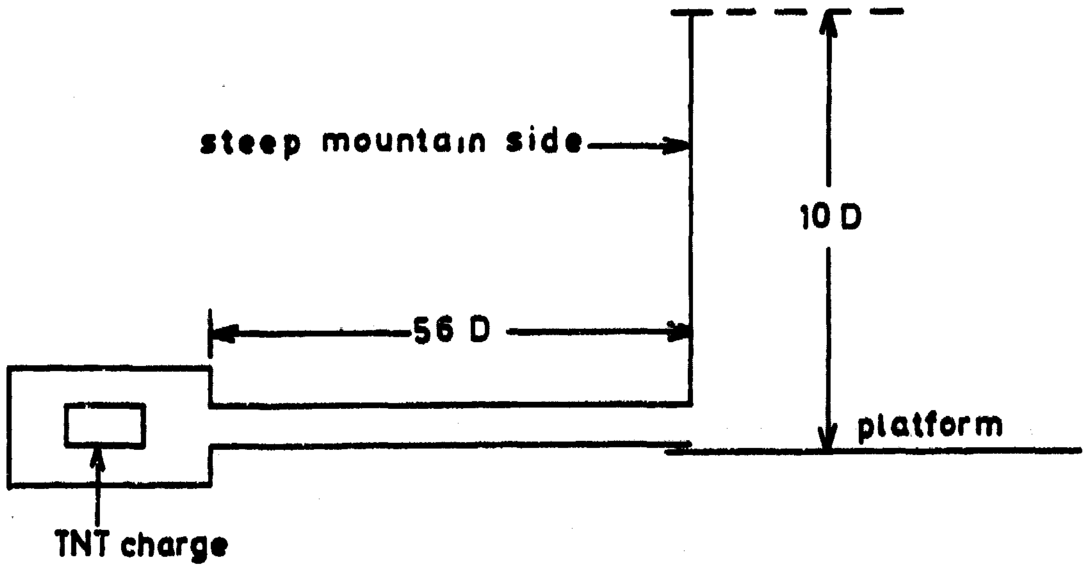
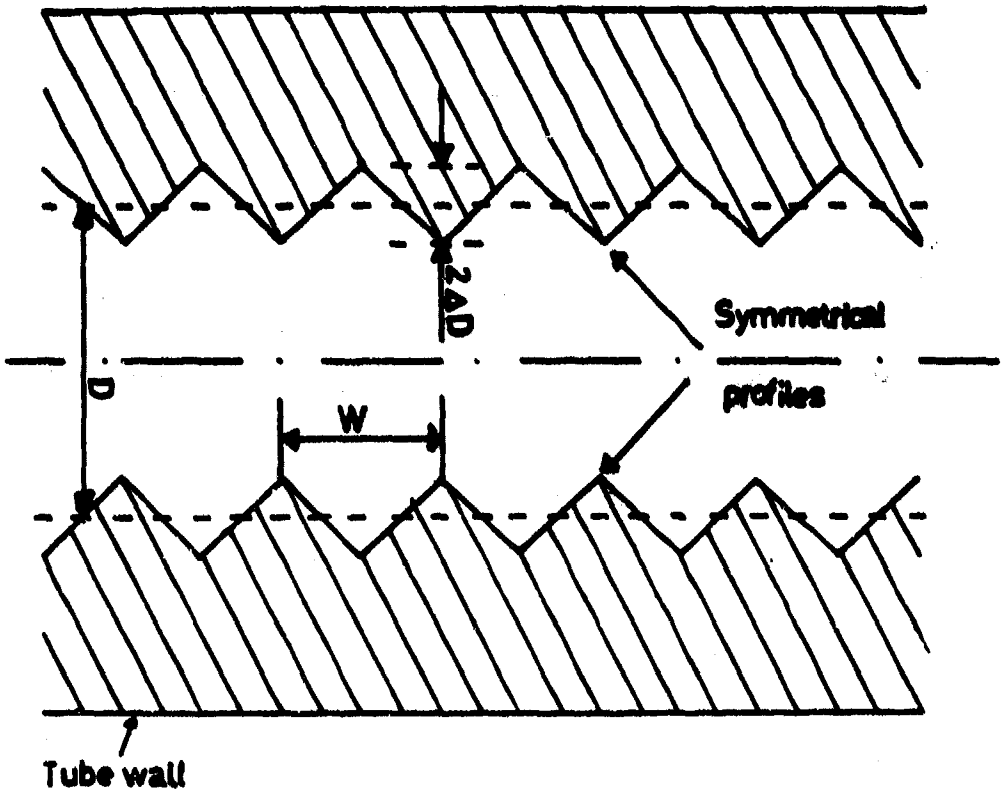


Figure 1b CFG 2 in principle



Definition of wall roughness: $r_i = \frac{\Delta D}{D}$

Scale	1/100	1/50	3/100
W(mm)	20	40	60

Figure 2 Definition of wall raughness

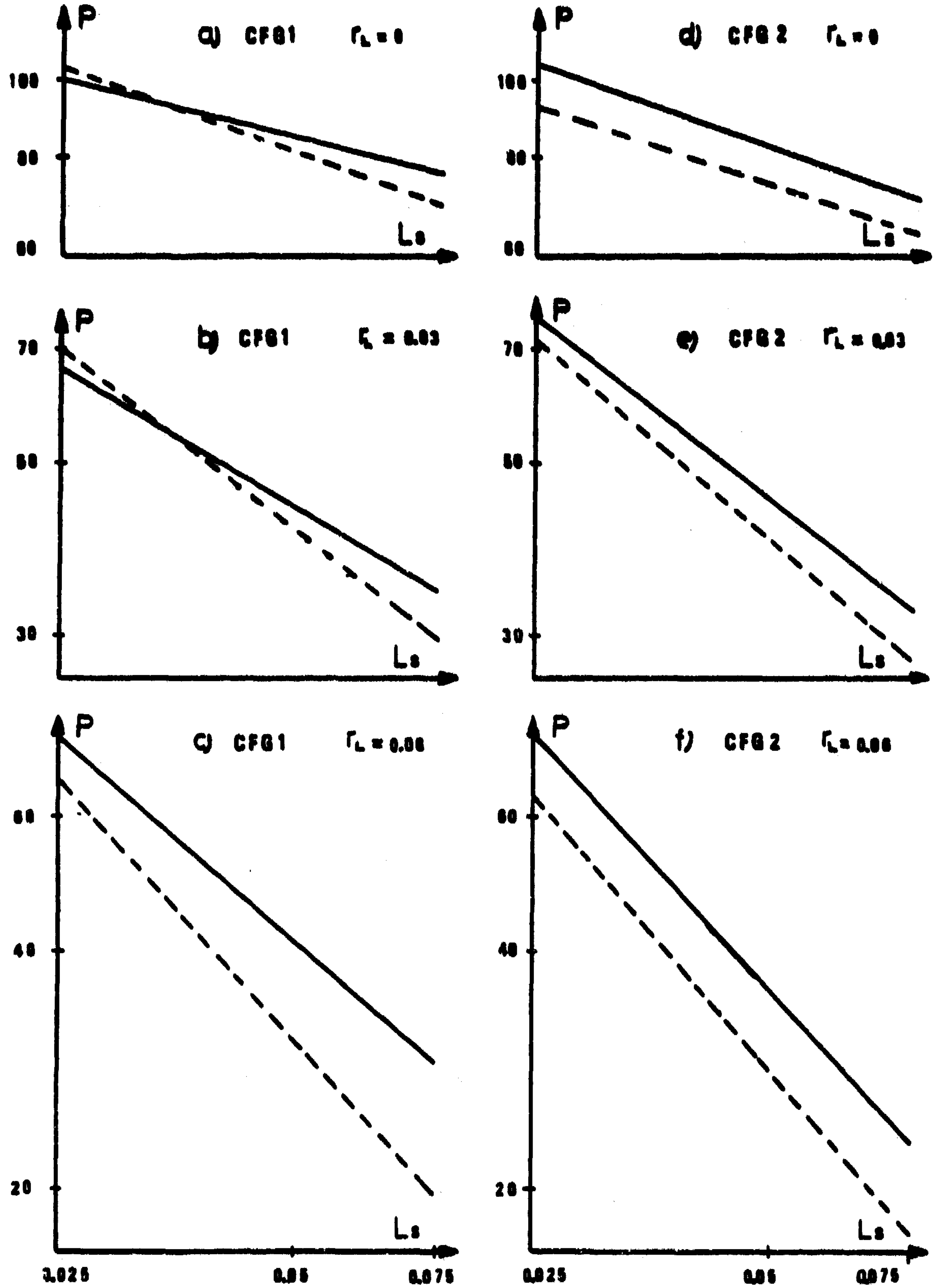
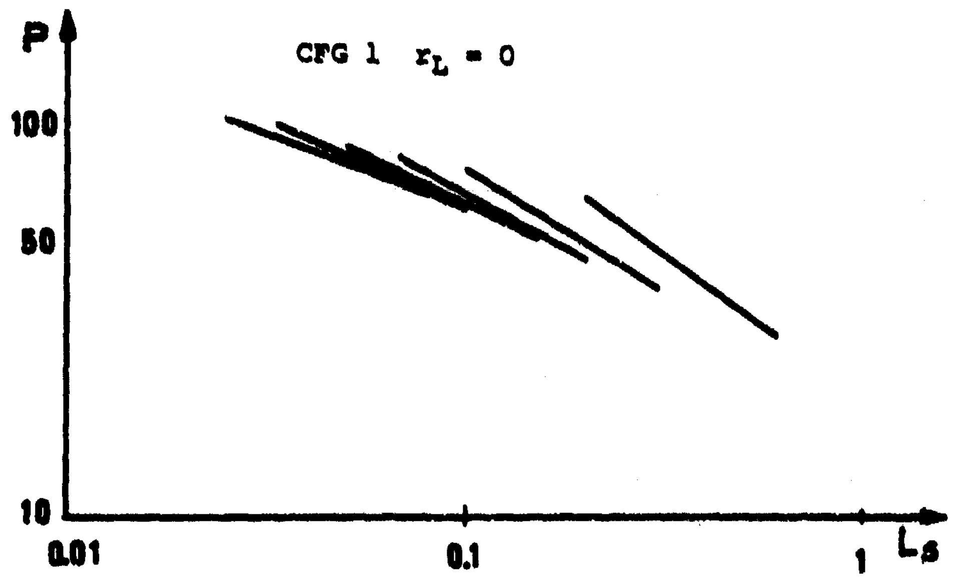


Figure 3 Front pressure vs scaled distance, q=640, —— 3:100 ---1:100



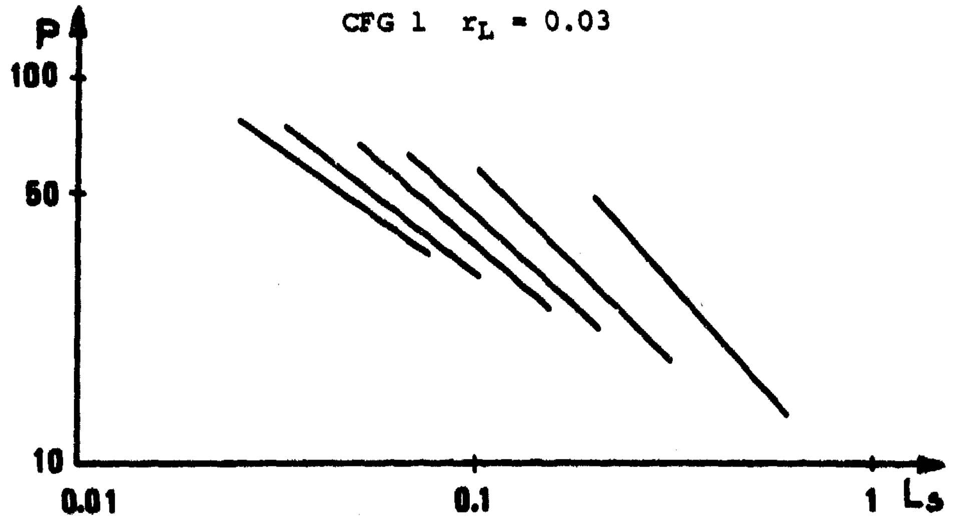


Figure 4a-b Front pressure vs scaled distance, 1:100. The curves are from left to right, q=640, 480, 320, 240, 160, 80.

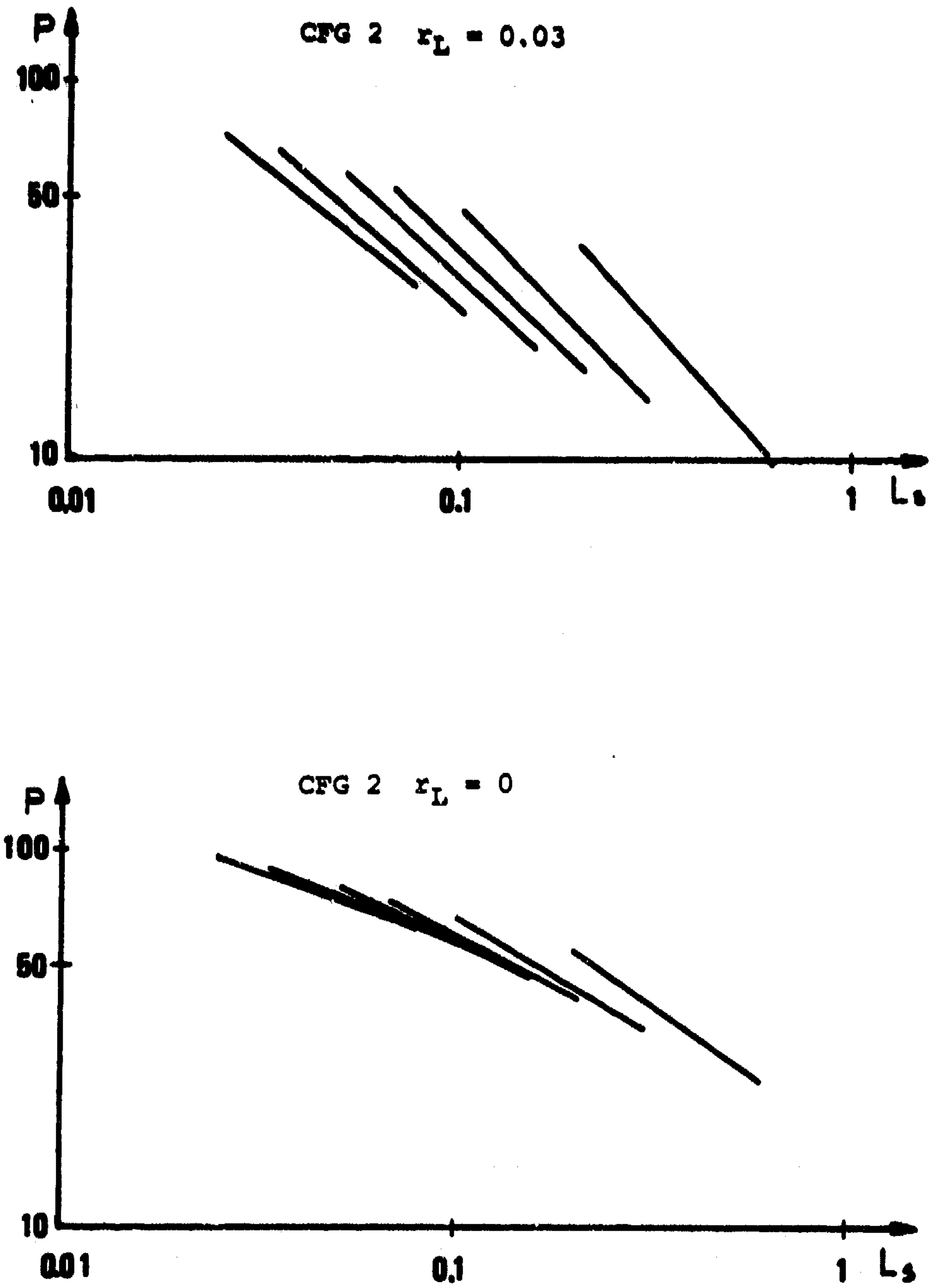


Figure 4c-d Front pressure vs scaled distance, 1:100. The curves are from left to right, q=640, 480, 320, 240, 160, 80.

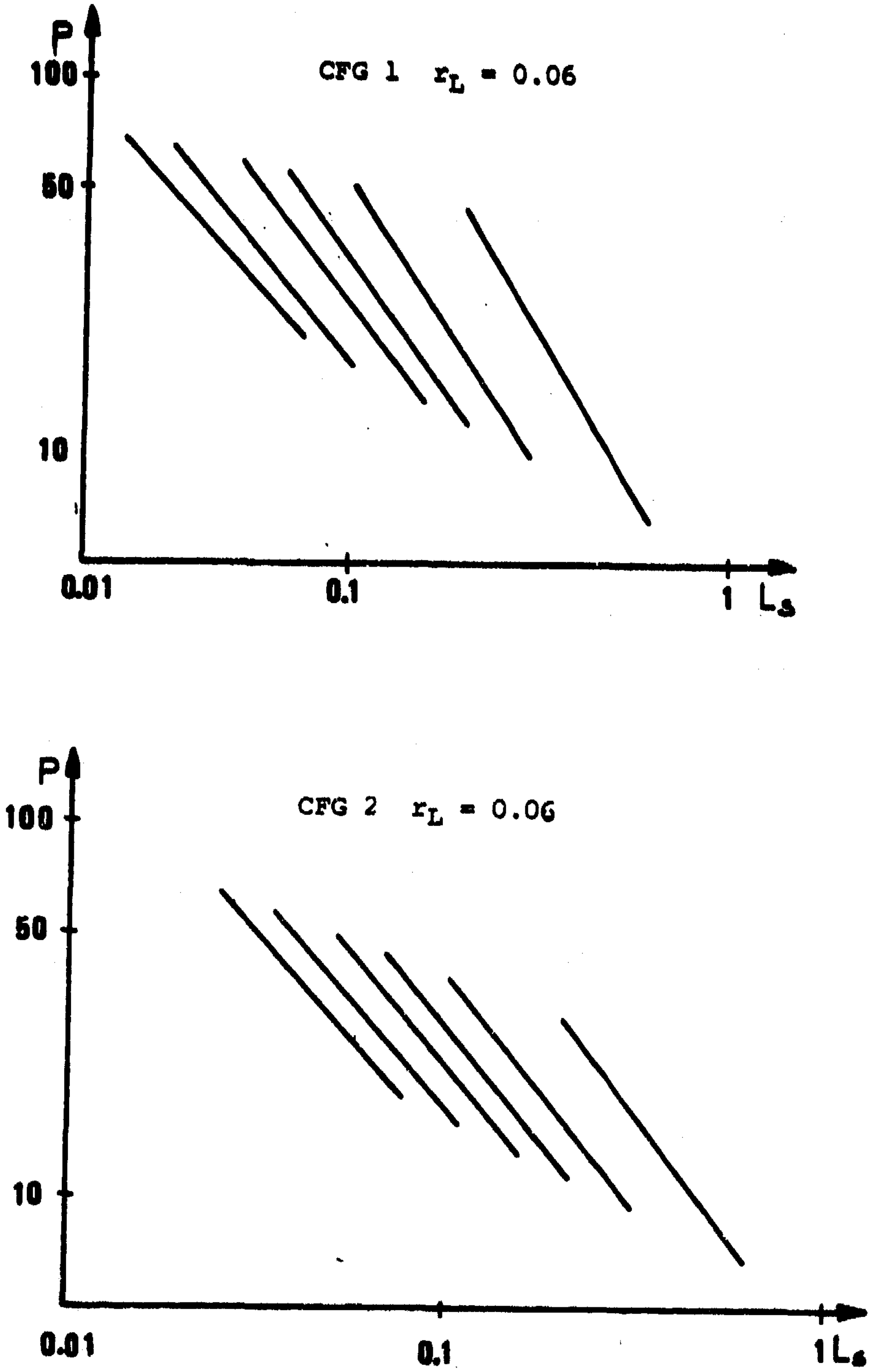


Figure 4e-f Front pressure vs scaled distance, 1:100. The curves are from left to right, q=640, 480, 320, 240, 160, 80.

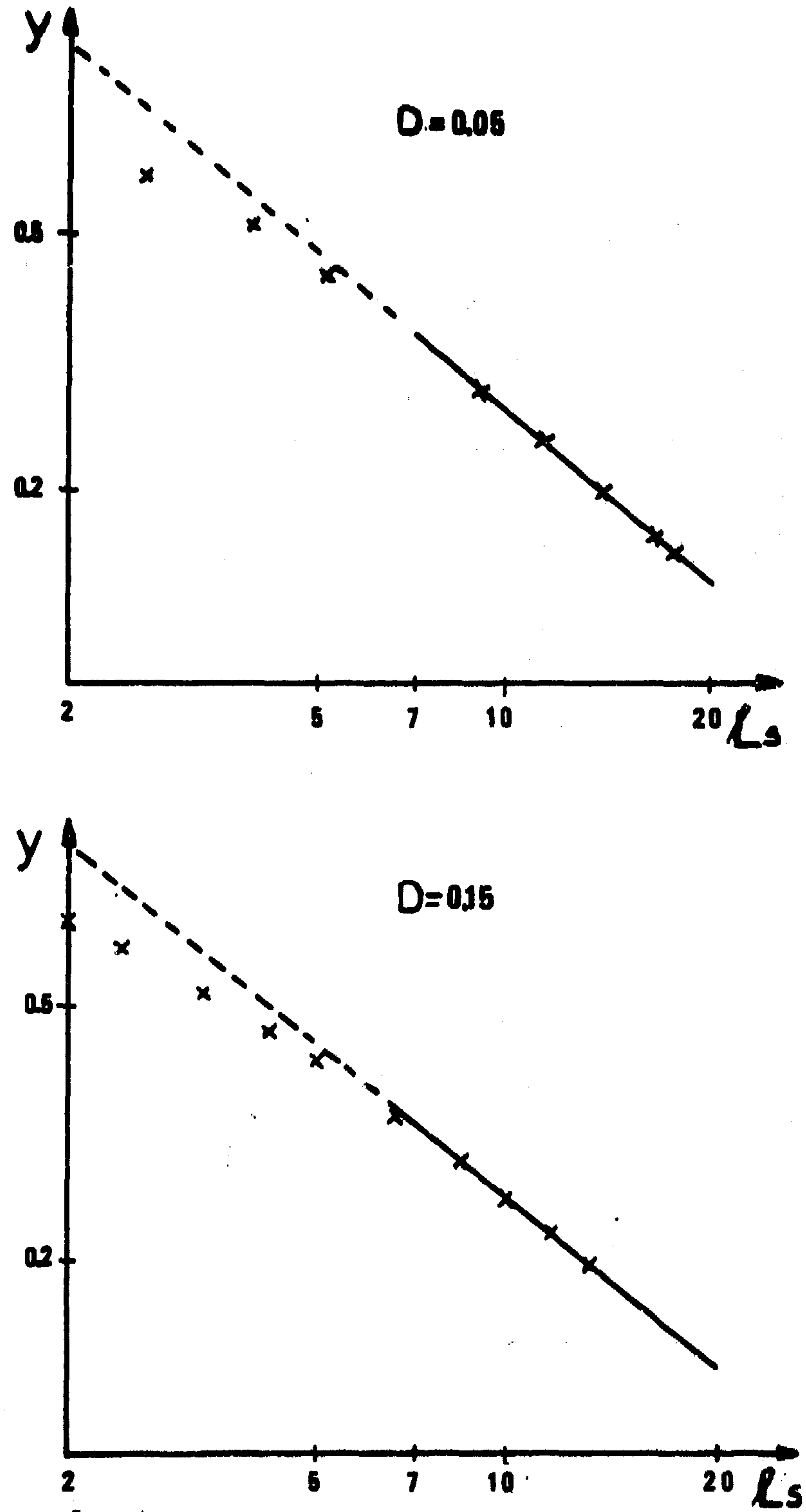


Figure 5 $y = \frac{L - a_o t}{L}$ vs l_s for q=480, r_L = 0, CFG 1. Recorded values of y and results from curve fitting of Eq. (20).

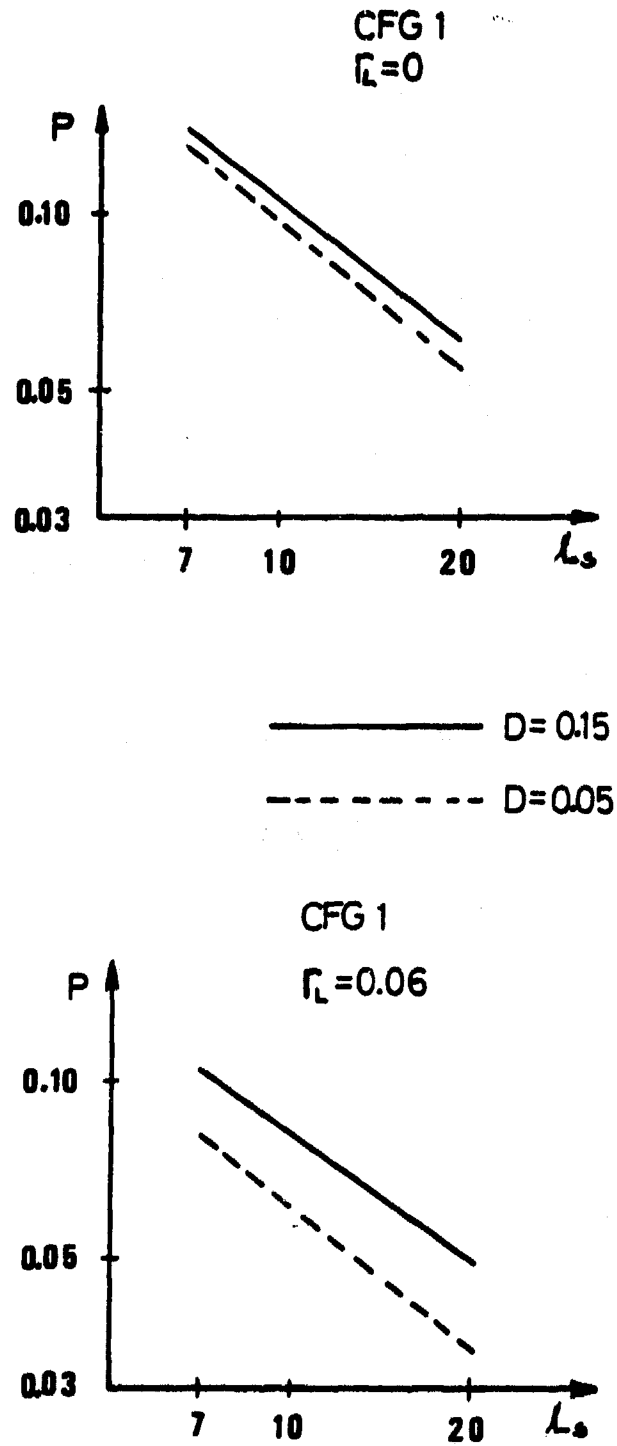


Figure 6 Shock propagation outside the tunnel. Scale dependence. Eqs. (23) and (24).

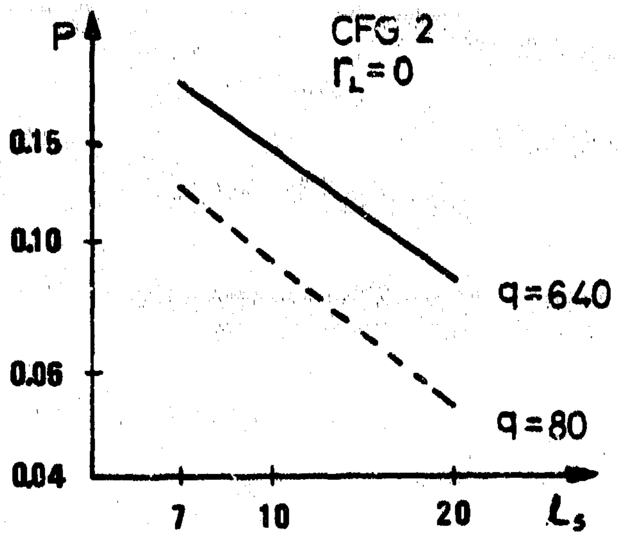


Figure 7 Shock propagation outside the tunnel. Dependence on charge group. Eqs. (25) and (26).

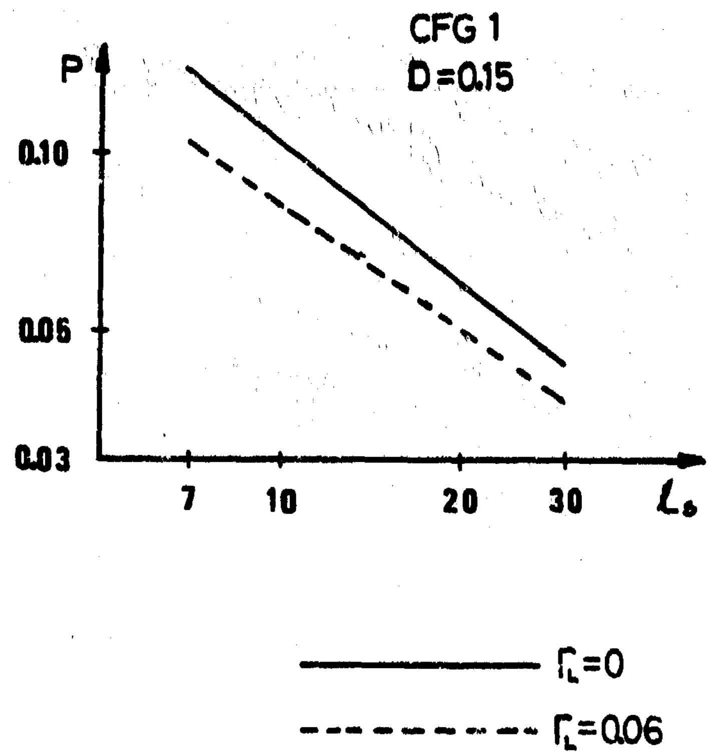


Figure 8 Shock propagation outside the tunnel. Dependence on roughness.

Q(kg)	q(kg/m^3)	80	160	240	320	480	640
D(m)	0.05	0.010	0.020	0.030	0.040	0.060	0.080
	0.10	0.080	0.160	0.240	0.320	0.480	0.640
	0.15	0.270	0.540	0.810	1.080	1.620	2.160

Table 1 Charges used in the experiments.

ε (%)	50	20	10	5	2	1	0.2
C	0.67	1.28	1.65	1.96	2.33	2.58	3.09

Table 2 Test level and percentage points of Student's T-distribution. DF = ∞.

	r_L	α_1	T	$\alpha_2 \cdot 10^2$	T	$\alpha_3 \cdot 10$	T	α'_1	T	$\alpha'_2 \cdot 10^4$	T	$\alpha'_3 \cdot 10^2$	T
CFG 1	0	33	4.53	-3.1	5.37	-1.1	1.31	-0.7	3.91	4.4	3.75	0.6	3.62
	0.03	18	3.59	-4.1	9.97	-4.5	7.34	-0.4	0.98	2.5	0.97	5.5	14.20
	0.06	71	15.00	-4.3	11.07	-7.9	13.53	-1.5	2.83	8.5	2.58	12.8	26.20
CFG 2	0	64	9.09	-3.8	5.04	-2.6	2.03	-2.4	9.61	4.4	2.69	1.4	7.46
	0.03	33	6.34	-6.2	11.27	-1.7	1.74	-3.8	5.21	23.5	4.59	4.2	7.31
	0.06	50	12.76	-6.6	15.72	-4.4	6.17	-0.8	1.32	47.0	10.27	6.5	13.57

Table 3 Values of the α-parameters from Eqs (12) and (13).

	r_L	e^{β_1}	β_2	T	β_3	β_4	β_5	T	β_6	T
CFG 1	0	66	-0.02	0.63	0.22	0.74	-0.09	2.73	-0.18	8.90
	0.03	49	-0.04	1.46	0.23	1.17	-0.12	3.10	-0.21	7.85
	0.06	44	0.12	3.02	0.21	1.73	-0.20	3.88	-0.30	8.32
CFG 2	0	54	0.13	4.96	0.26	0.73	0.04	1.30	-0.20	8.31
	0.03	37	0.07	1.88	0.32	1.15	-0.05	0.97	-0.15	4.45
	0.06	29	0.17	5.01	0.38	1.34	-0.07	1.46	-0.08	2.50

Table 4 β-values from Eq. (15).

	CFG 1			CFG 2		
r_L	0	0.03	0.06	0	0.03	0.06
β_1	0.83	0.81	0.82	0.80	0.78	0.78
β_2	-0.021	-0.042	-0.075	-0.034	-0.039	-0.063
T	3.98	5.22	7.73	3.30	3.25	4.36

Table 5 Scale dependence of B. Eq. (23).

	CFG 1			CFG 2		
r_L	0	0.03	0.06	0	0.03	0.06
β_1	0.056	0.044	0.035	0.065	0.045	0.043
β_2	0.041	0.090	0.229	0.048	0.136	0.124
T	1.42	2.06	4.26	0.95	1.83	1.68

Table 6 Scale dependence of (1-B)K. Eq. (24).

	CFG 1			CFG 2		
r_L	0	0.03	0.06	0	0.03	0.06
β_1	0.83	0.79	0.78	0.82	0.75	0.74
β_2	-0.008	-0.005	-0.002	-0.035	0.004	0.007
T	2.45	0.70	0.18	5.69	0.40	0.56

Table 7 Dependence of B on charge group. Eq. (25).

	CFG 1			CFG 2		
r_L	0	0.03	0.06	0	0.03	0.06
β_1	0.055	0.040	0.039	0.054	0.044	0.043
β_2	0.050	0.110	0.033	0.196	0.091	0.057
T	3.19	2.95	0.80	8.90	1.81	1.06

Table 8 Dependence of (1-B)K on charge group. Eq. (26).

	CFG.1			CFG.2		
r_L	0	0.03	0.06	0	0.03	0.06
$\overline{(1-B)K}$	0.058	0.047	0.041	0.067	0.050	0.047
$\bar{B}$	0.82	0.79	0.78	0.79	0.76	0.74

Table 9 Mean values of Band $(1-B)K$

	CFG.1			CFG.2		
r_L	0	0.03	0.06	0	0.03	0.06
β_1	24	18	14	30	20	18
β_2	0.08	0.18	0.38	0.12	0.24	0.29
T	1.89	2.78	4.91	1.43	2.21	2.48

Table 10 Dependence of scaled 50 mbar limit, l_{50}, on D. Eq (27).

	CFG.1			CFG.2		
x_L	0	0.03	0.06	0	0.03	0.06
β_1	23	19	16	23	20	20
β_2	0.07	0.07	0.04	0.31	0.11	0.06
T	3.08	1.54	0.61	8.05	1.42	0.67

Tabel 11 Dependence of scaled 50 mbar limit, l_{50} on q. Eq (28).

AN INVESTIGATION OF BLASTWAVE PENETRATION INTO A TUNNEL ENTRANCE

by

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ABSTRACT

A situation is simulated in model tests, assuming that explosives are transported into an underground ammunition storage and an accidental explosion happens in front of the tunnel entrance. A blastwave penetrates into the tunnel and propagates along the main passageway. The blast parameters are measured at distances between 10 and 100 times the tunnel diameter from the entrance. The blast parameters in the tunnel can be related to the charge mass, the charge distance from tunnel entrance and the orientation of elongated charges relative to the tunnel axis.

I. INTRODUCTION

An explosive charge or ammunition may detonate very close to the entrance of an underground ammunition storage. In this investigation it is assumed that the tunnel entrance is covered into the fireball of the explosion. Blast data inside the tunnel are needed in order to dimension blast doors at the ammunition storage chambers.

The complicated three-dimensional shock- and pressure pattern around the tunnel entrance cannot be performed by theoretical calculation. Full scale tests are too expensive to solve this problem. Therefore small scale model tests are performed.

Data from shock tube tests are available for the penetration of airblast in tunnels in the far field of nuclear explosions. The shockwave parameters at the entrance are pretended in that case. Results are lacking for the near field of HE detonations.

II. TEST ARRANGEMENT

A model was built simulating an underground tunnel in a hill-side with a flat platform in front of the tunnel entrance. The model consists primarily of a straight tube leading to a steel-platform and a hillplate with 90° slope. The smooth circular steel tube has a diameter of D = 0.088 meter and a sectional area of F = 0.006 square meter. The total tube length amounts to 150 tube diameters. Pressure measurements are made at 16 locations inside the tube between 10 and 100 diameters from the entrance, mostly in a 5 diameter distance from each other. The rest of 50 diameters ensures that no effect from the tube end affects the measurement.

As shown in Figs. 1 and 2 elongated charges are detonated outside the tunnel entrance at the platform. The charge center is located 1,2 or 3 tunnel diameters outside the entrance in direction of the tunnel axis. In arrangement 1 the charge axis is brought in direction of the tunnel axis and perpendicular to that in arrangement q. The results of six different test arrangements are referred to as 11, 21, 31, 1q, 2q, 3q.

III. EXPLOSION SOURCE

Uncased cylindrical charges with length to diameter ratios between 5 and 7 were prepared for the tests. Pure RDX (Hexogen) together with 3 % of wax were pressed to explosive charges at $1{,}6 \cdot 10^{3}$ kg m^{-3} volumetric weight. Microsecond igniters of type No. 8 (Dynamit Nobel) were used.

Charges at six different weights 5g, 13g, 29g, 40g, 53g and 83g were made for the tests with the 0.088 m diameter tube. A total number of 80 shots was performed in the test series. Each test arrangement together with any charge mass was tested at least two times.

IV. INSTRUMENTATION

If we whish to record the side-on time history of the pressure in the blast wave inside the tube, we have to mount transducers as smooth as possible in the wall. Transducers must not interfere seriously the flow behind the shock front. Only miniature pressure transducers are suited for small scale model tests.

There are primarily four phenomena which lead to difficulties in pressure measurements: rise time, overshoot, accelleration- and temperature sensitivity of the gauges. The natural frequency of the transducers is about 500 kc. After amplification we send the signals through a 150 kc Bessel characteristic filter in order to control the overshoot. Accelleration sensitivity of the gages is reduced by accelleration compensation. In spite of that, accelleration must be controlled by careful design of the model and accurate mounting of the pressure transducers in adapters. To reduce the gage response to radiative and conductive temperature, the gage diaphragm is covered with a thin layer of black silicone rubber. Thus a compromise on the requirements of gage dynamics and heat protection is found. The rise-time is checked for each pressure-time history and is found to be 25 microseconds or less.

In order to have available an integrated instrumentation system for blast pressure measurements a 16 channel transient recorder is used. The digitalized data are stored at tape cassettes for further treatment at the computer. The complete instrumentation system is carefully calibrated before and after the test series in a shock tube device and the stability is found to be better than 5 %.

V. DATA REDUCTION

A total number of 800 records is used as a basis for the investigation. If the digitalized record of one shot is fed into the computer some blast parameters can be easily calculated: shock front time of arrival TA, rise time and mean shock front velocity U from time of travel between two

measuring locations. The pressure-time history is integrated and the impulse-time history as well as the total blast impulse are available. Much more effort is necessary to find out the peak side-on overpressure PO, the positive duration T+ and a description of the pressure-time history as a function of time. A computer-aided data reduction procedure delivers a complete set of blast parameters.

VI. SCALING

For the design of protective structures we need blast data in tunnels of several meters in diameter. The model-test results are utilizable only if they can be scaled to full scale dimensions. From our experience with detonations inside tunnels we know, that blast scaling works satisfactorily. As we have to take into consideration at least two independent scaled parameters, the conversion from one tube dimension to another is more complicated than in the case of free-air burst.

No obligatory format for the presentation of results is known. The results of this investigation are presented in the form of approximation formulae related to a tube of 1 square meter cross sectional area corresponding to D_1 = 1,128 meters tunnel diameter. The nondimensional distance parameter, overpressure and velocity at corresponding positions can be taken directly for any tunnel dimension, whilst time and blast-impulse have to be converted by the linear conversion factor. Charge mass has to be converted by the cube of the linear conversion factor.

VII. EVALUATION

Logarithmic plots of peak overpressures and blast-impulses are presented in Figs. 3 to 7. The nondimensional distance parameter at the abscissa varies from 10 to 100. Inside the tube, 10 diameters from the entrance, the shock wave and flow field are essentially one-dimensional and the pressure measurements can be described by few parameters. It is a remarkable characteristic of this test arrangement that peak pressure measurements from pressure gages can be checked by shockfront velocity measurements. Shockfront velocity between any neighboring gages can be converted to peak overpressure by shock relations. Two essentially independent data sets for peak overpressure in Figs. 3 to 5 correspond perfectly.

Six different test arrangements are investigated, each of them at six charge masses. A total of 36 curves for any parameter is available. An example for the low peak overpressure range less then 5 bars is shown in Fig. 3. The charge center is located two tunnel diameters in front of the entrance with the charge axis in direction of the tunnel axis (2 1). Charge mass amounts to 28 kg for an 1 square meter tube. Diagrams for the medium pressure range up to 15 bar and high pressure range up to 80 bar are presented in Figs. 4 and 5. Results of correlation calculations are recorded in any diagram. At least up to 30 bars the peak pressure measurements can be approximated quite well by power functions. The exponent of the power function will be named β. A considerable decrease of peak overpressure is to be observed as the blastwave runs down the tube.

The blast impulses of the positive pressure phases for two test arrangements (1 1 and 1 q) and six charge masses at

either arrangement are presented in Figs. 6 and 7. Blast impulses grow with increasing charge mass, but remain essentially constant at any point in the tube for one charge mass. The constant blast impulse is an argument to know that no choking has occurred in the model tube - and therefore the results can be scaled up to prototype dimensions.

The cylindrical charges at 85.4 kg and 112 kg in Fig. 6 have the same diameter but different lengths. The blast impulses, as well as the peak overpressures, are the same in both tests. This observation indicates that the charge shape is an important parameter.

Figures 8 and 9 show, how the peak overpressure at the point L/D = 10 varies with charge mass for the six test arrangements. These results also can be approximated by power functions. The listed values of P_{10} are taken from the approximation formulae as shown in Figs. 3 to 5.

VIII. RESULTS

It was found from the data evaluation that the exponent β which describes the peak overpressure attenuation e.g. in Figs. 3 to 5, is correlated with the peak overpressure at the point L/D = 10. The higher the peak overpressure P_{10} the higher is the exponent β, which means steeper pressure decrease. This result, together with an approximation formulae, is shown in Fig. 10. If one knows the pressure P_{10} for one of the arrangements from Figs. 8 or 9, and the exponent β from Fig. 10, thus the peak overpressure at any point in the tunnel can easily be calculated. An

example for such a calculation and the comparison with experimental data is shown in Fig. 12(printed together with Fig. 5 at one page). The author is anxious to prove, whether this result is transferable to other test arrangements. Preliminary the result must not be applied to test-arrangements different from those described here.

The blast impulse of the positive pressure phase as well is correlated with the P_{10}-pressure, as shown in Fig. 11. Thus, if one knows the P_{10}-pressure and the approximation formulae for the exponent β, the most important parameters for protective design can be determined at any point in the tunnel.

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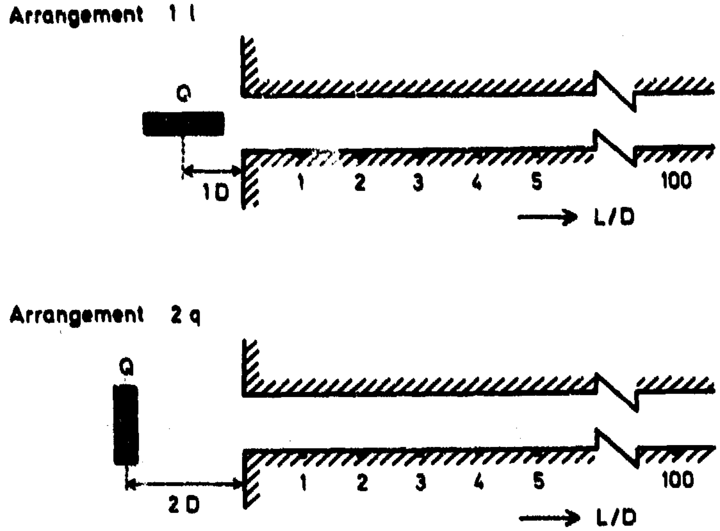


Fig. 1
Top Plan of the Test Arrangement

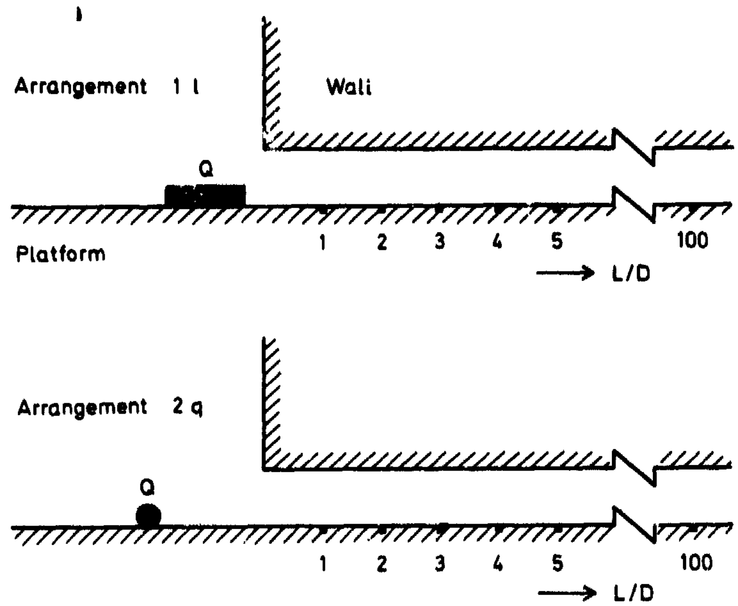


Fig. 2 Side View of the Test Arrangement

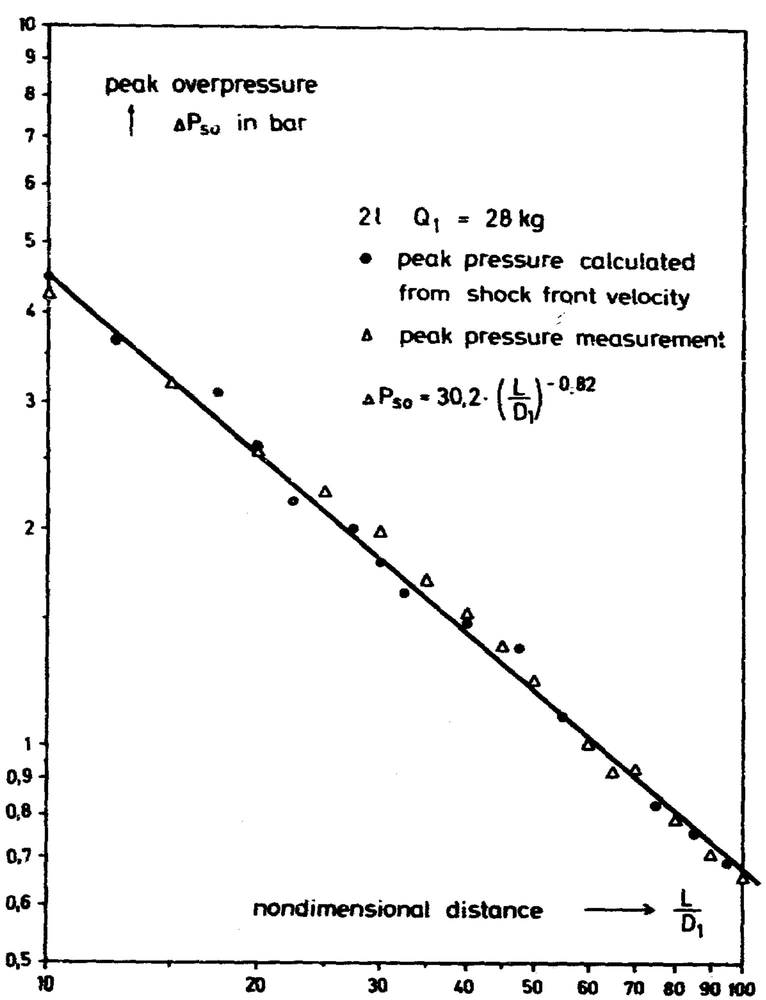


Fig. 3

Blast wave propagation in a straight, smooth tunnel. Peak overpressure versus distance from the tunnel entrance

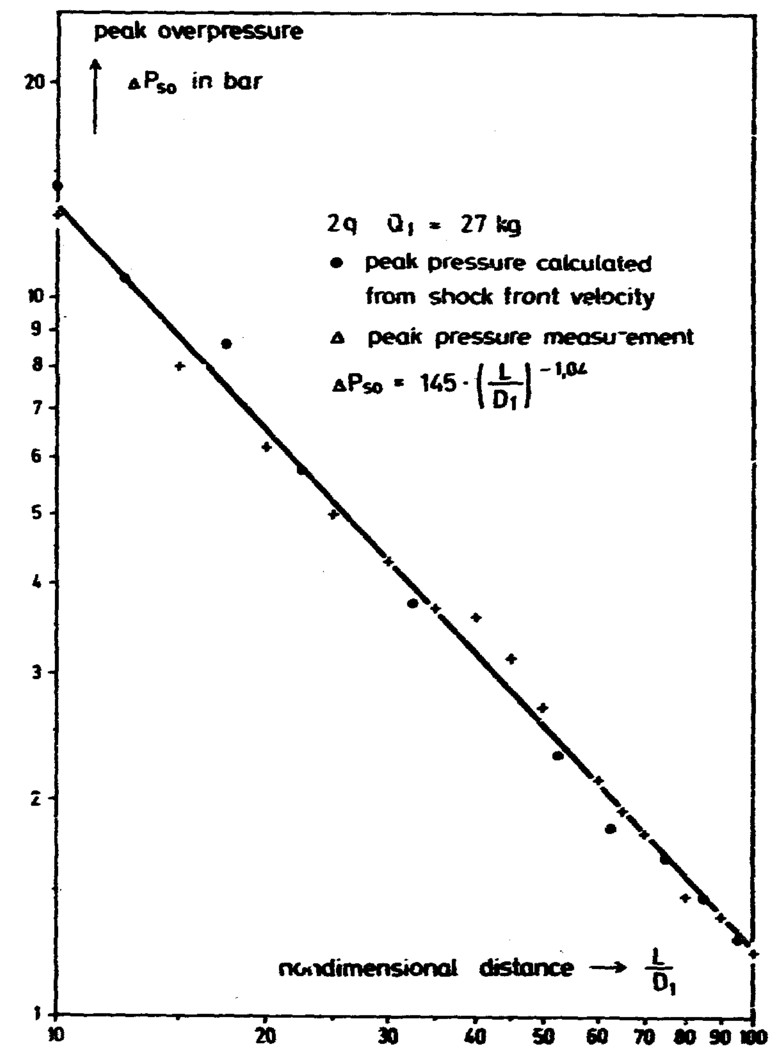


Fig. 4

Blast wave propagation in a straight, smooth tunnel. Peak overpressure versus distance from the tunnel entrance

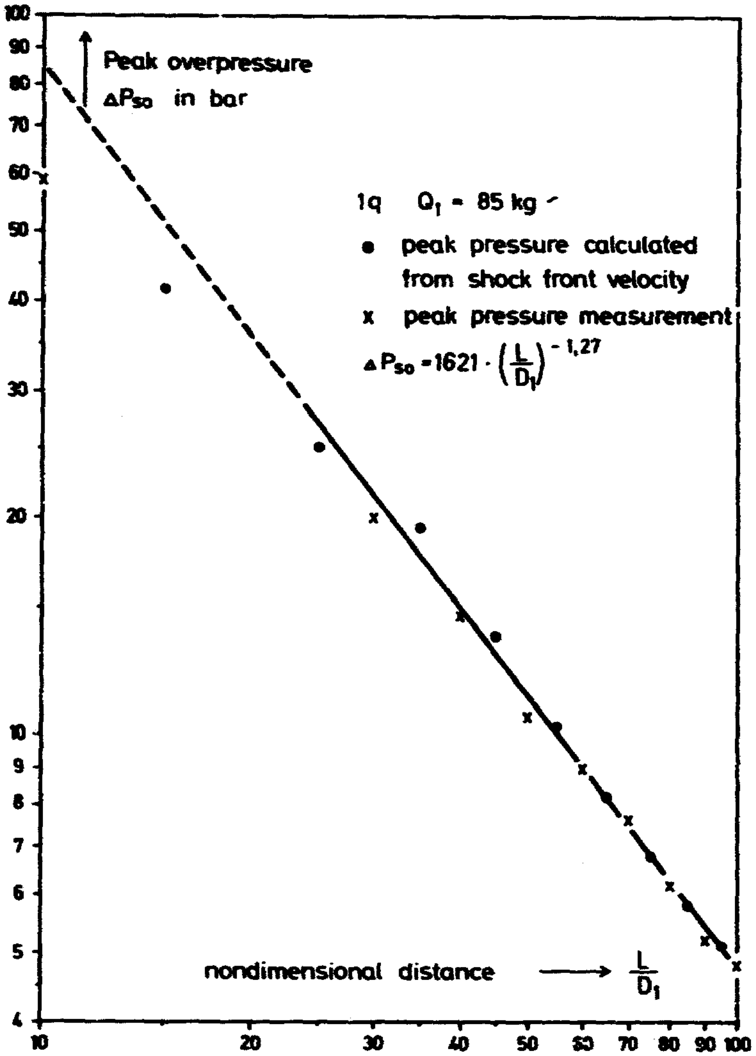


Fig. 5

Blast wave propagation in a straight, smooth tunnel. Peak overpressure versus distance from the tunnel entrance

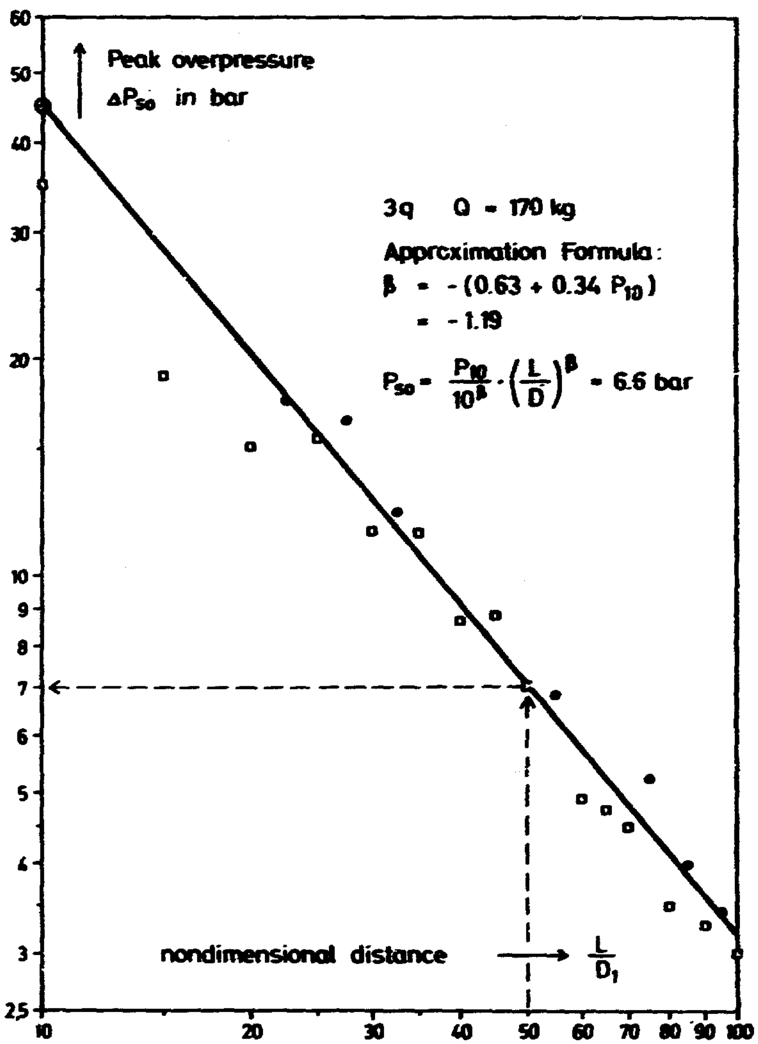


Fig. 12

Peak overpressure versus distance from the tunnel entrance

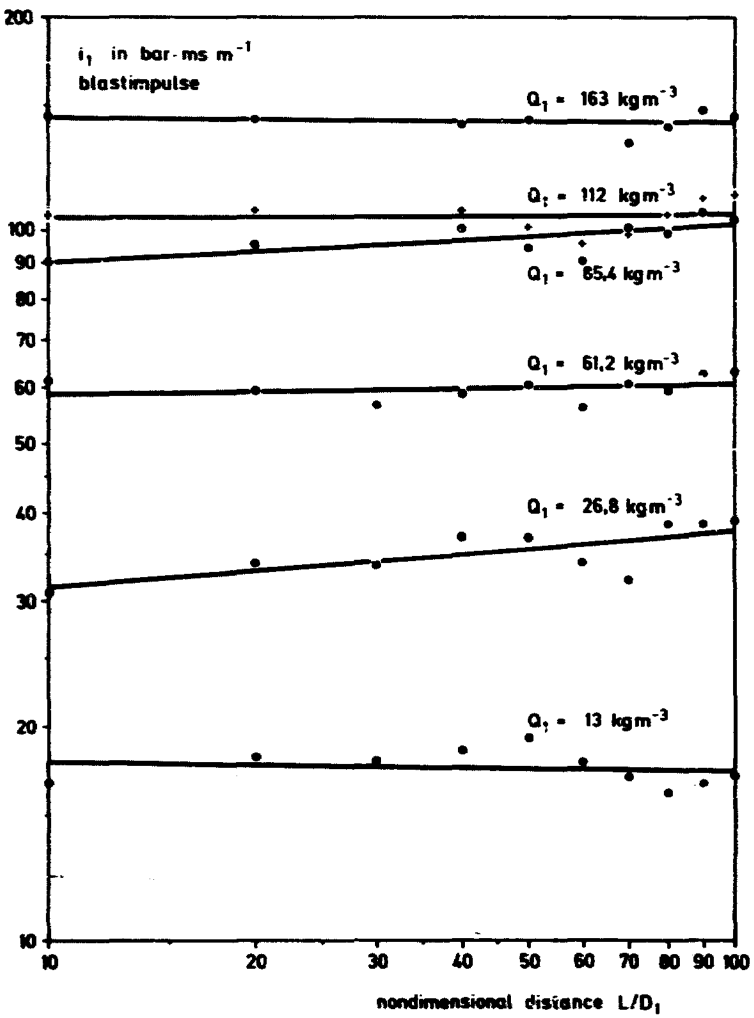


Fig. 6

Blastimpulse of the positive pressure phase versus distance. Test arrangement 1 l

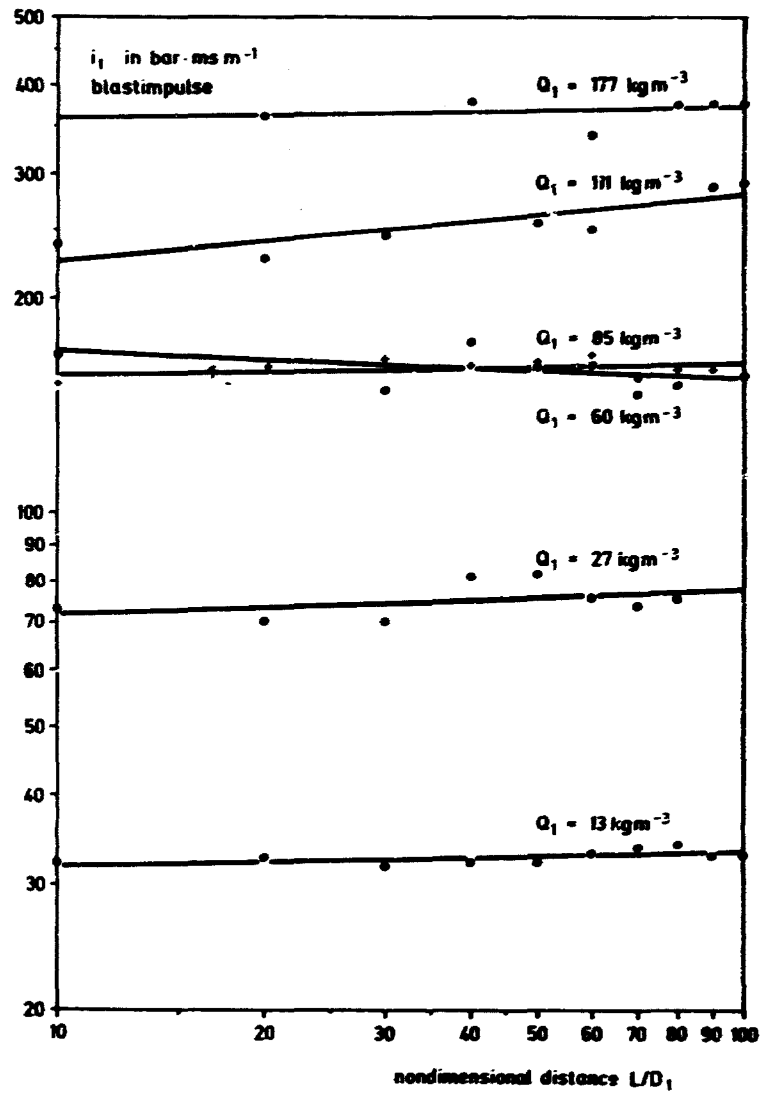


Fig. 7

Blastimpulse of the positive pressure phase versus distance. Test arrangement 1q

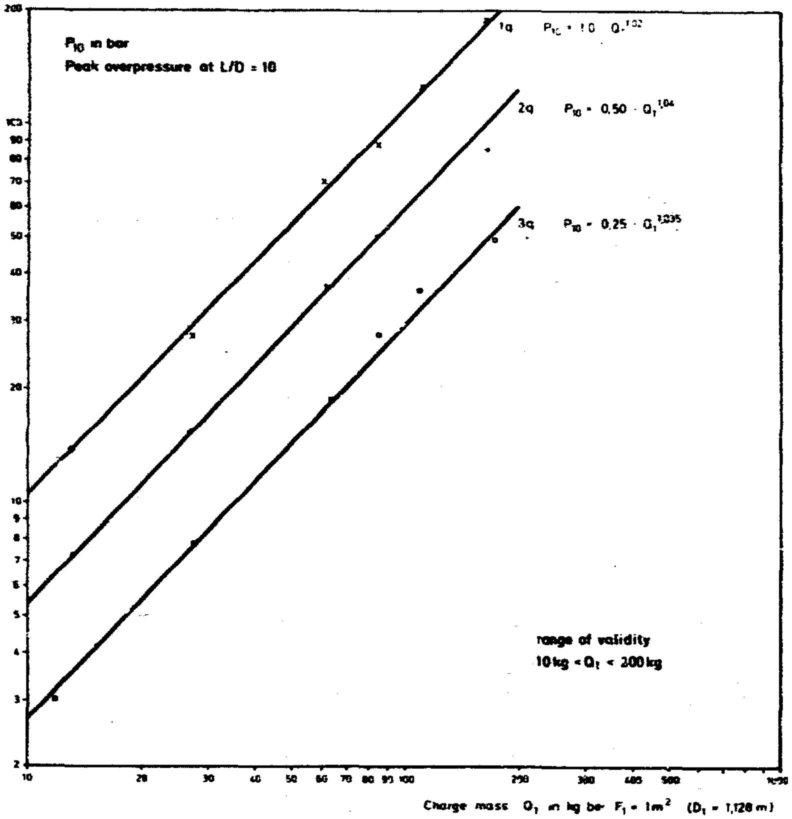


Fig. 9

Peak overpressure in the tube at L/D = 10 versus charge mass. Elongated charges are oriented perpendicular to the tunnel axis

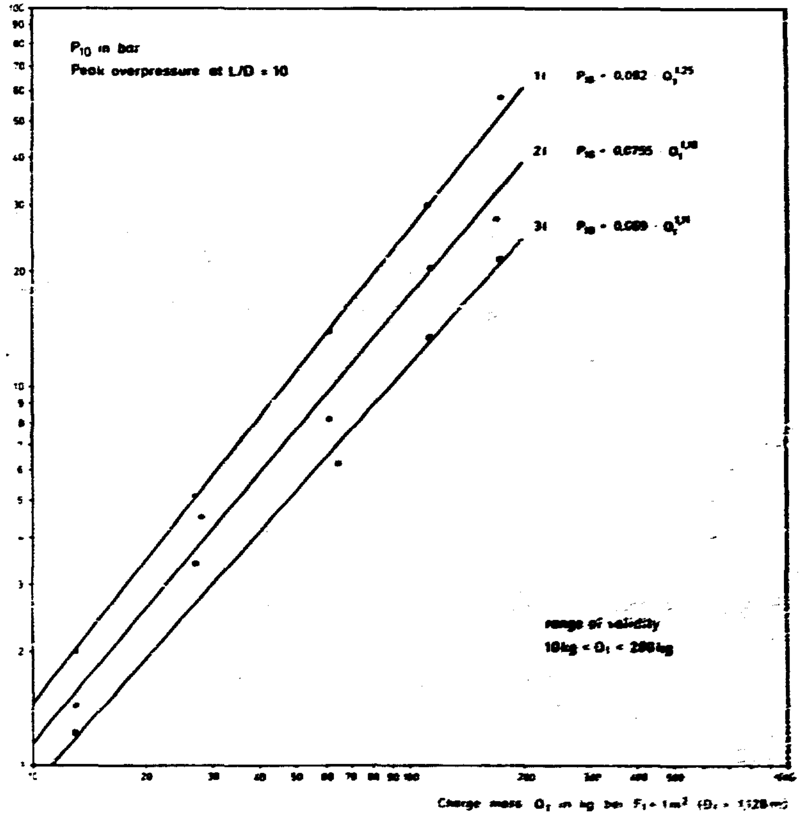
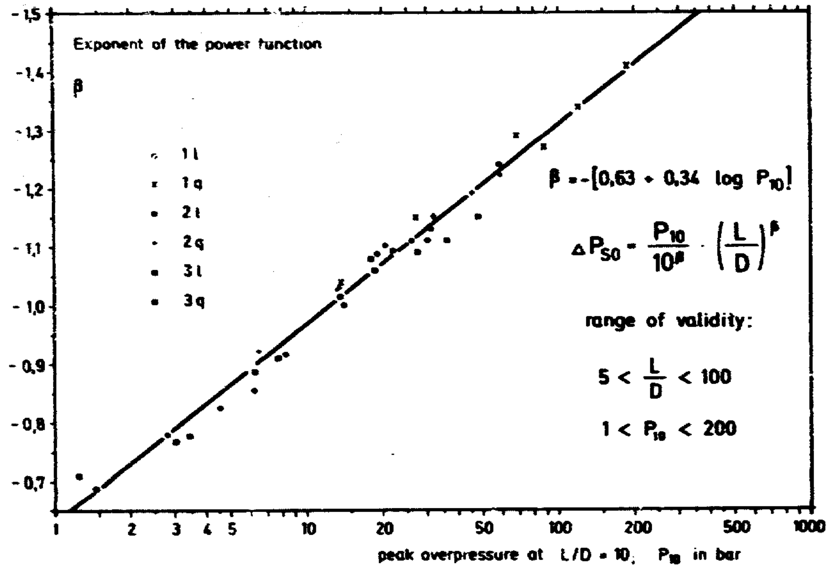


Fig. 8

Peak overpressure in the tube at L/D = 10 versus charge mass. Elongated charges are oriented with their longitudinal axes in direction of tunnel axis



$\Delta P_{SO} = \frac{P_{10}}{10^{\beta}} \cdot \left(\frac{L}{D}\right)^{\beta}$

$5 < \frac{L}{D} < 100$

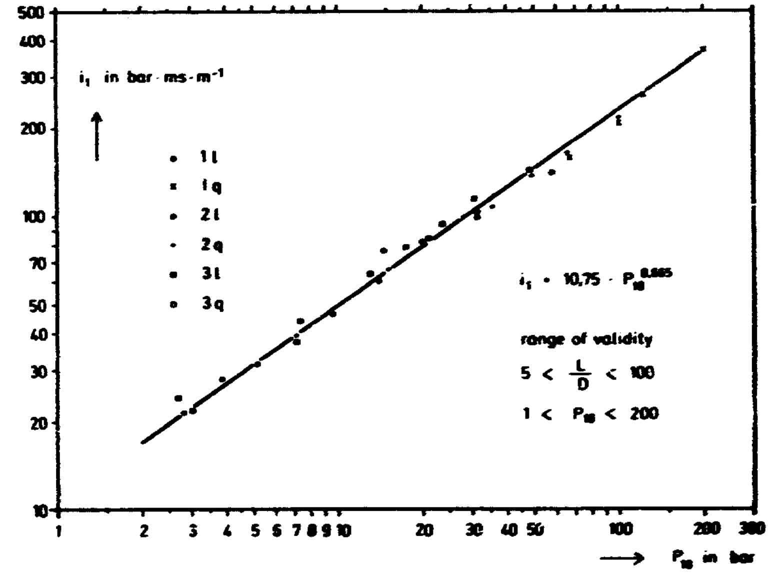
$1 < P_{10} < 200$

Fig. 10

Peak overpressure in the tube as a function of P_{10} and L/D.

The exponent β versus P_{10}.

Valid for 6 different test arrangements.



$i_1 = 10{,}75 \cdot P_{10}^{0{,}885}$

$5 < \frac{L}{D} < 100$

$1 < P_{10} < 200$

Fig. 11

Blastimpulse of the positive pressure phase as a function of P_{10} for any point in the tunnel

EXPLOSIVE INITIATION FROM FRAGMENT IMPACT

by

Peter S. Westine

INTRODUCTION

A variety of criteria have been used in the past when trying to predict the threshold of initiation for fragments and other projectiles penetrating explosive. The word initiation as used in this discussion can mean either deflagration or detonation since in either process a violent reaction occurs which destroys the explosive. This problem of explosive initiation is further complicated when the explosive is encased in a shell or box. In this paper, we will take the approach that no one mode or process for initiation is sufficient. In uncased (bare) explosive charges and in cased explosives under the correct combination of input conditions, detonation can be caused by the high pressures of shock waves initiated during the impact. The initiation of explosive in this shock initiation domain occurs rapidly and is not affected by confinement except for the influence of layered media on the propagation of the high pressure waves in the explosive. Geometry, shock impedance, impact velocity, and explosive sensitivity are all important in this shock initiation domain. The ability of a fragment to penetrate a casing has no influence on explosive initiation in this shock initiated domain.

Under other combinations of conditions, much less severe than those required for shock initiation, confined explosive charges can still be initiated. Dr. Philip Howe (Ref. 1) has hypothesized that for the impact of cased or confined explosives, a second mode of initiation may occur which is caused by perforation of the casing. In this perforation mode, the thermal processes associated with extrusion of explosive into cracks in a failed casing cause a violent reaction to spread through an encased explosive charge. This perforation mode of initiation cannot occur in a bare charge, and it will be quenched if the confinement is removed too rapidly.

In this paper we will suggest an explosive initiation criteria that can include initiation by both modes, that is, shock initiation and casing perforation. We will attempt to show what conditions are needed for one

mode to change to the other and we will present approximate derivation procedures which help to explain why parameters interrelate as they do in different domains.

Figure 1 is a four-parameter space of nondimensional numbers which presents criteria for both modes of initiation. The solid continuous lines are the threshold for initiation by shock and the series of dashed contours are the threshold for initiation by casing perforation. In Figure 1, all symbols are defined in the legend of the figure. The ordinate relates the velocity and diameter of the fragment to the sensitivity of the explosive, the abscissa relates the thickness of the casing to the diameter of the fragment, the dashed contours relate the penetration resistance of the casing to the explosive sensitivity, and the solid contours are for different impedance matches between casing and penetrator.

The series of arrows demonstrates how the explosive initiation threshold would change modes for a specific case. First, one has the casing perforation mode of initiation until with larger values of h/d, the contour intersects the shock initiation threshold which then dominates. If the scaled velocity of impact is less than that given by both modes for a given value of h/d, the explosive should not initiate. On the other hand, if the scaled velocity of impact is greater than either one of the thresholds, the explosive should be initiated.

A bare explosive initiation threshold can be obtained from Figure 1 by setting h/d equal to zero and $\rho_c u_c / \rho_p u_p$ equal to 1.0, which gives the correct ordinate limit of 6.75. The solution presented in Figure 1 assumes normal impact of a cylindrical fragment on a flat casing. In later discussions, we will show how this solution can be modified to account for the effect of wave focusing caused by the impact of curved casing surfaces such as those in artillery shells, bombs, etc.

DERIVATION OF A SHOCK INITIATION RELATIONSHIP

The first mode of initiation discussed was initiation by shock. This mode of initiation is given by the solid contours in Figure 1. The criteria which will be used is the Livermore (Ref. 2) criteria which relates the logarithmic value of the shock distance propagated into an explosive with the logarithmic value of the shock front pressure. Figure 2 presents

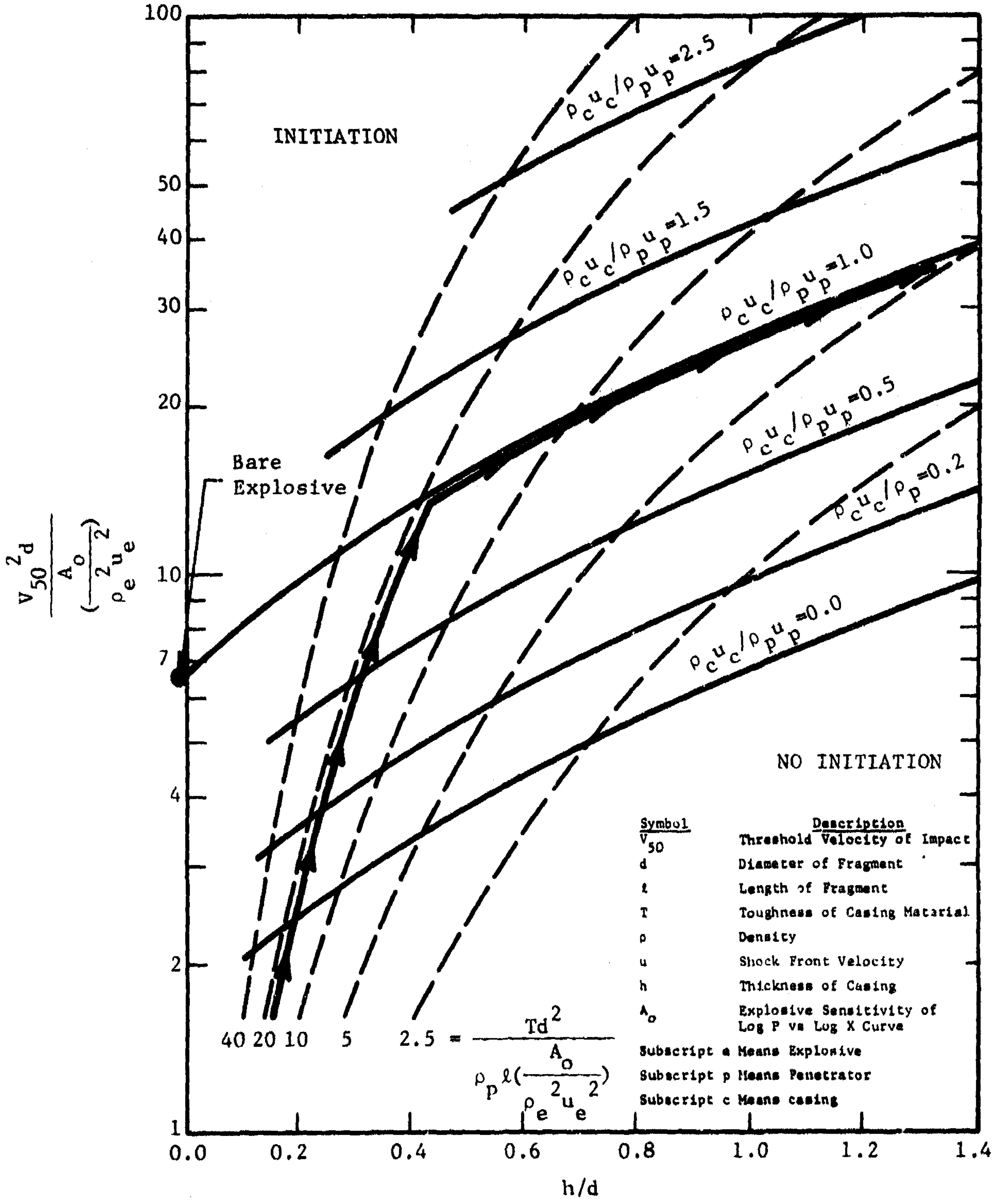


FIGURE 1. EXPLOSIVE INITIATION THRESHOLDS AND DOMAINS

Symbol	Description
V_{50}	Threshold Velocity of Impact
d	Diameter of Fragment
ℓ	Length of Fragment
T	Toughness of Casing Material
ρ	Density
u	Shock Front Velocity
h	Thickness of Casing
A_o	Explosive Sensitivity of Log P vs Log X Curve

Subscript e Means Explosive

Subscript p Means Penetrator

Subscript c Means casing

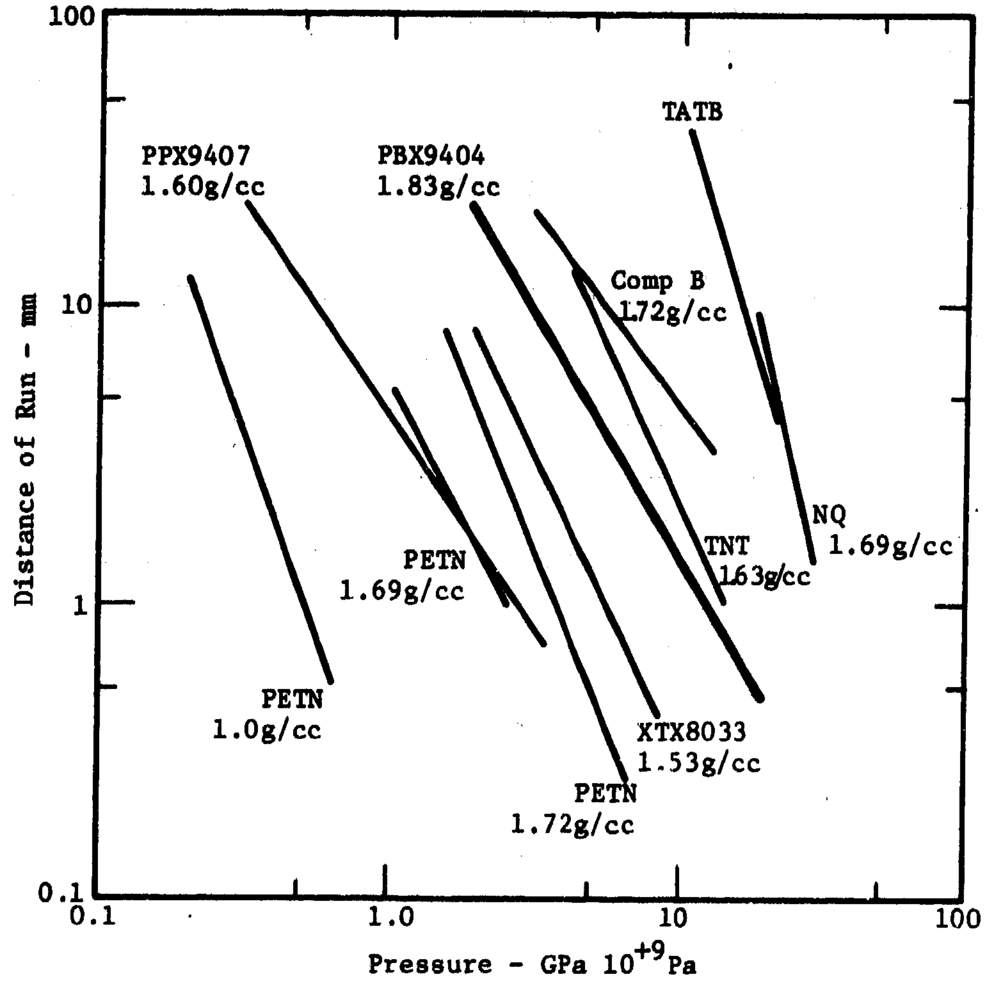


FIGURE 2. DISTANCE OF RUN TO DETONATION VS INITIAL SHOCK PRESSURE FOR VARIOUS EXPLOSIVES (REFERENCE 3)

experimentally determined thresholds for a variety of shock load explosives. Because the threshold is a straight line on log-log paper, the distance X_d and initiation pressure P_d can be interrelated as in Equation (1) below:

$$X_d P_d^{\alpha} = A \tag{1}$$

where α is the slope and A is the explosive sensitivity intercept.

For the explosives shown in Figure 2, the slope α ranges from 1.3 to 3.0 with a reasonably average slope of 2.0. If α is assumed to equal 2.0, the sensitivity intercept A will equal A_o whose dimensions in the English system will be lb^2/in^3. For Comp B, A_o equals approximately $3.5 \times 10^{+11}$, and for PBX-9404, A_o equals approximately $9.1 \times 10^{+10}$ lb^2/in^3.

Next we need to evaluate the geometric dissipation of the shock strength with distance as the shock wave propagates into a bare explosive. If X_i is the distance into a medium, P_i is the pressure at distance X_i, P_o is the impact pressure, and d_o is the diameter of a cylindrical fragment which impacts the explosive normally, then the pressure under the impact point and at distance X_i can be assumed to relate according to Equation (2):

$$\frac{P_o}{P_i} = \frac{(d_o + X_i)^{\beta}}{(d_o)^{\beta}} \tag{2}$$

where β is a dissipative exponent probably falling between 1.0 and 2.0. Subsequent experimental data will show that β equal to 3/2 fits test results excellently. Assuming that β equals 3/2 and rearranging Equation (2) algebraically gives Equation (3) for shock wave dissipation:

$$\frac{P_i}{P_o} = \left(1 + \frac{X_i}{d_o}\right)^{-3/2} \tag{3}$$

Dividing Equation (1) by $P_o^2 d_o$ to nondimensionalize the shock initiation criteria in a similar fashion as Equation (3) gives:

$$\left(\frac{P_d}{P_o}\right)^2 \left(\frac{X_d}{d_o}\right) = \left[\frac{A_o}{P_o^2 d_o}\right] = C \tag{4}$$

When initiation occurs, Equations 3 and 4 will have the same values for P_d and P_i. In addition, the slopes dP/dX will be equal at the threshold of initiation. These two criteria give two equations which, when solved, give

C and X for the threshold of initiation. The quantity that interests us is C which at initiation equals 6.75. Because C is defined by Equation (4), this result means that the explosive sensitivity, A_o, the shock pressure at the surface of the explosive, P_o, and the diameter of the impacted region on the surface of explosive, d_o, are all interrelated by:

$$P_o^2 d_o = 6.75\ A_o \tag{5}$$

Now we are ready to solve for shock initiation in a cased explosive as in Figure 3. At the top of the casing, the initial impact pressure, P_{C1}, will be:

$$P_{C1} = \frac{\rho_c u_c V_{50}}{(1 + \frac{\rho_c u_c}{\rho_p u_p})} \tag{6}$$

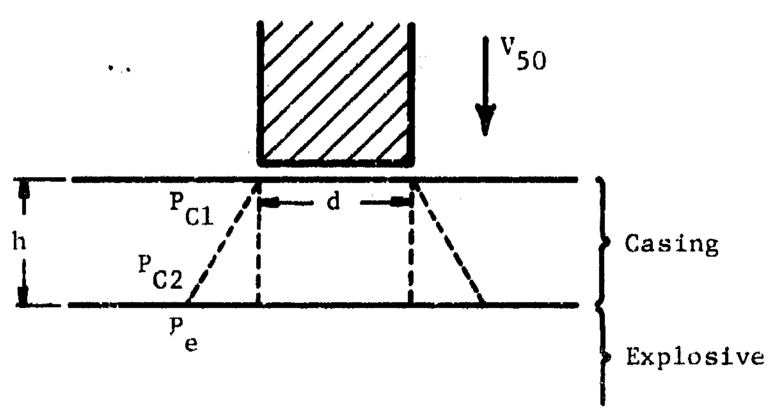


FIGURE 3. IMPACT ON A CASED EXPLOSIVE

If we dissipate this pressure using the 3/2 power law as given by Equation (3), at the bottom of the casing the pressure P_{C2} will be given by:

$$P_{C2} = \frac{\rho_c u_c V_{50}}{(1 + \frac{\rho_c u_c}{\rho_p u_p})} \left(\frac{d}{d+h}\right)^{3/2} \tag{7}$$

In the explosive itself, the pressure will differ from that in the casing because of the impedance differences between the casing and the explosive. A transmitted stress, σ_t, relates to the incident stress, σ_i, by the relationship:

$$\frac{\sigma_t}{\sigma_i} = \frac{2}{(1 + \frac{\rho_i u_i}{\rho_t u_t})} \qquad (8)$$

Substituting Equation (7) into Equation (8) gives:

$$P_e = \frac{2\rho_c u_c V_{50}}{(1 + \frac{\rho_c u_c}{\rho_p u_p})(1 + \frac{\rho_c u_c}{\rho_e u_e})(1 + \frac{h}{d})^{3/2}} \qquad (9)$$

Finally, by recognizing that P_e equals P_o and (d+h) equals d_o in Equation (5), substituting Equation (9) into Equation (5), and recognizing that $\rho_e u_e$ is very small relative to $\rho_c u_c$, the following relationship is obtained:

$$\frac{\rho_e^2 u_e^2 V_{50}^2 d}{A_o} = 1.688\ (1 + \frac{\rho_c u_c}{\rho_p u_p})^2 (1 + \frac{h}{d})^2 \qquad (10)$$

Equation (1) is the relationship plotted as solid contours in Figure 1. The left hand side of Equation (1) is the ordinate, h/d is plotted as an abscissa, and the contours are for various constant values of $\rho_c u_c/\rho_p u_p$.

Although we do not go through the algebra to prove this statement, the reader can obtain the solution for a layered system by propagating and transmitting waves through different layers. In a layered system consisting of three layers, this solution would be given by the following equation where h is then the total thickness of all layers and the lowest numbered subscript layer contacts the impacting fragment.

$$\frac{\rho_e^2 u_e^2 V_{50}^2 d}{A_o} = 1.68(1+\frac{\rho_{C1} u_{C1}}{\rho_p u_p})^2 (1+\frac{\rho_{C2} u_{C2}}{\rho_{C1} u_{C1}})^2 (1+\frac{\rho_{C3} u_{C3}}{\rho_{C2} u_{C2}})^2 (1+\frac{h}{d})^2 \qquad (11)$$

The solution for fragment impact into a bare uncased explosive is given by:

$$\frac{\rho_e^2 u_e^2 V_{50}^2\ d}{A_o} = 6.75 \qquad (12)$$

This solution follows by substituting Equation (6) into Equation (5), setting $\rho_c u_c$ equal to $\rho_e u_e$, and assuming that $\rho_e u_e/\rho_p u_p$ is very small relative to 1.0. Equation (10) for cased explosive also gives this same limit, provided one assumes that the uncased solution can be represented by a

casing of zero thickness that has the same $\rho_c u_c$ as the penetrator $\rho_p u_p$.

This solution for shock initiation is very similar to one developed by Green (Ref. 2) of Livermore with the major exception being the dissipative relationship given by Equation (3). Dimensionally Green's solution would combine parameters into the same nondimensional ratios. Green's solution would have similar impedance matches, but would have a different exponent on (1 + h/d) and would have a numerical constant $\sqrt{2}$ times the h/d term. The solution proposed in this paper expands the wave front at an angle of 30 degrees; whereas, the Livermore solution expands it at an angle of 45 degrees. Qualitatively the solutions are similar, but quantitatively differences do exist. The best way of resolving these differences and any others is to compare predictions to test results.

COMPARISON WITH SHOCK INITIATION TEST RESULTS

Figures 4 and 5 are comparisons of $V_{50}{}^2 d$ versus $(1 + h/d)^2$ for steel fragments fired into either steel cover plates over explosive or into bare explosive. Under these conditions Equation (10) for encased explosive and Equation (12) for bare explosive can both be presented in the form:

$$\left(\frac{V_{50}}{u_p}\right)^2 d = \text{constant } (1 + h/d)^2 \qquad (13)$$

The data in Figures 4 and 5 are from different sources (Ref. 4, 5, 6) in the literature and are for two explosives -- Comp B and Tetryl. Both bare and cased explosives are included in the curves and scatter does occur; however, the $(1 = h/d)^2$ relationship passes through most of the data. The constant is a function of ρ, u, and the explosive sensitivity, A_o, but these parameters are not being varied in these comparisons. In essence the different intercepts for these two explosives is a measure of the sensitivity of Comp B and Tetryl.

Perhaps the most carefully conducted set of shock explosive initiation test results are those by Livermore personnel on PBX-9404 (Ref. 2). In addition to tests on bare PBX-9404, shots were also fired into explosives with three different casings. One casing was 2 mm of tantalum, the second was 6 mm of tantalum, and the third casing was a three-layer composite of 1.27 mm of aluminum, 1.42 mm of polyurethane, and 8.40 mm of polycarbonate.

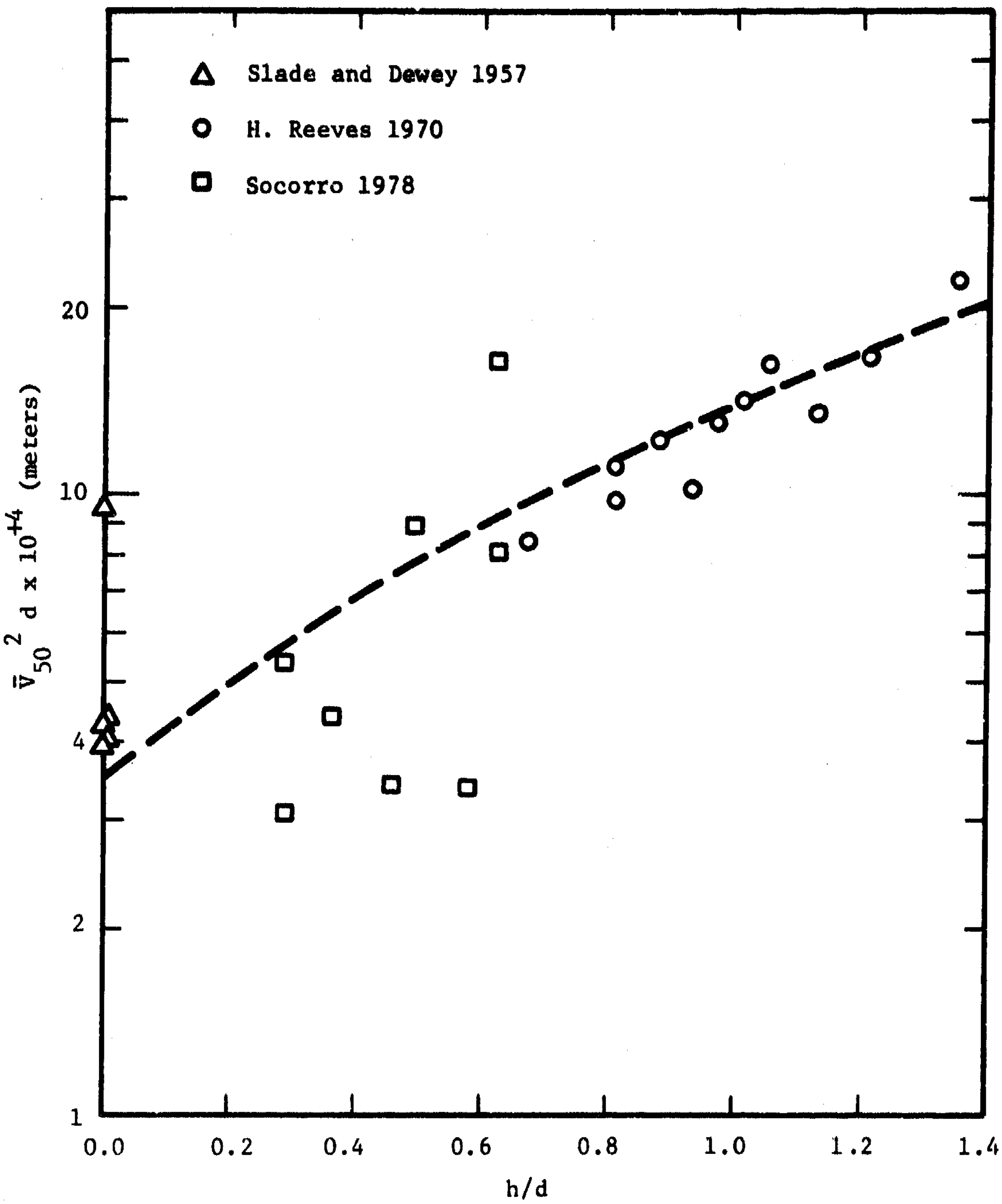


FIGURE 4. SHOCK INITIATION OF COMP B

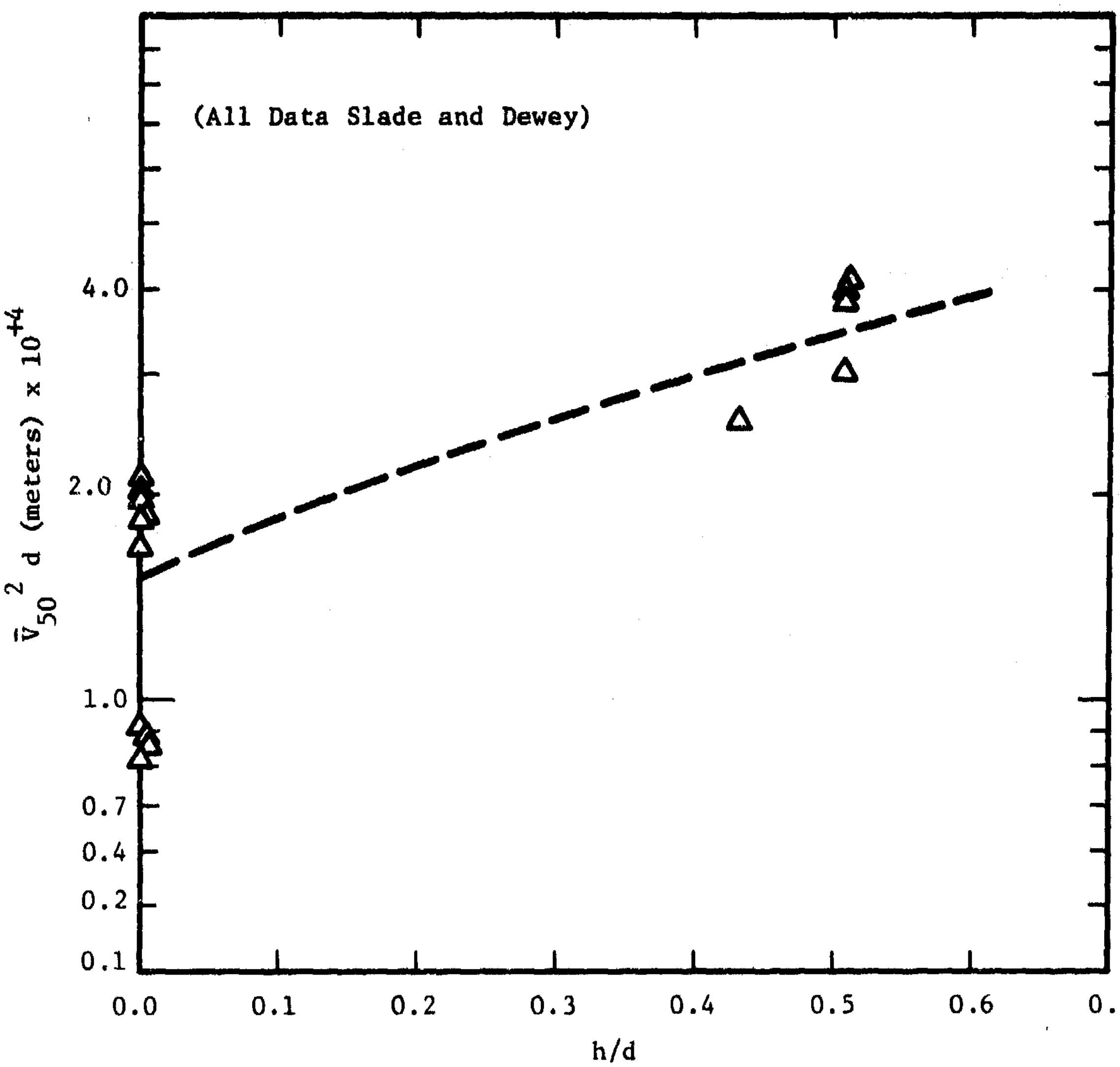


FIGURE 5. SHOCK INITIATION OF TETRYL

Steel fragments of different diameters were used to give a variation in h/d. By recognizing that ρ_e, u_e, and A_o remain constant in these experiments and by rearranging Equation (10) in the following format, these test results, shown in Figure 6, can be compared to our solution. This PBX-9404 agreement is even better than that shown for Comp B and Tetryl.

$$\frac{V_{50}^{2}d}{[1 + \frac{\rho_c u_c}{\rho_p u_p}]^2} = \text{constant } [1 + h/d]^2 \tag{14}$$

The test results in Figure 6 indicate that the constant in Equation (14) is 0.043 $km^2 in/sec^2$. Because this constant equals $1.688A_o/\rho_e^2 u_e^2$, the shock initiation sensitivity constant A_o can be calculated from this result. For PBX-9404, the density equals 1.83 gm/cc and the Rankine-Hugoniot conditions for this explosive relate shock front velocity u_s in km/sec to particle velocity u_p in km/sec with the following equation:

$$u_s = 2.31 + 2.767\ u_p \tag{15}$$

For an impact velocity around 1.75 km/sec, Equation (15) means the shock front velocity u_s is approximately 7.15 km/sec. After adjusting values so that a self consistent set of units is obtained, the results in Figure 6 indicate that the shock initiation sensitivity constant A_o for PBX-9404 is $9.1 \times 10^{+10}\ lb^2/in^3$. This value is equal to that found in Figure 2 for this explosive and discussed in the accompanying text.

DERIVATION OF CASING PENETRATION CRITERIA

The second cased explosive initiation mode was developed by Howe (Ref. 1) at BRL for explosive initiation from fragment penetration of the casing. To analytically derive this relationship, no explosive properties are needed. A simple energy balance can be performed in which the kinetic energy of the penetrator is equated to the strain energy needed to shear a circular disk out of the casing. The kinetic energy KE equals:

$$KE = \frac{mV_{50}^{2}}{2} = \frac{\pi d^2 \ell \rho_p V_{50}^{2}}{8} \tag{15}$$

The strain energy SE for a casing with a shear strength of τ that fails after the plug being sheared has moved half a casing thickness is given by:

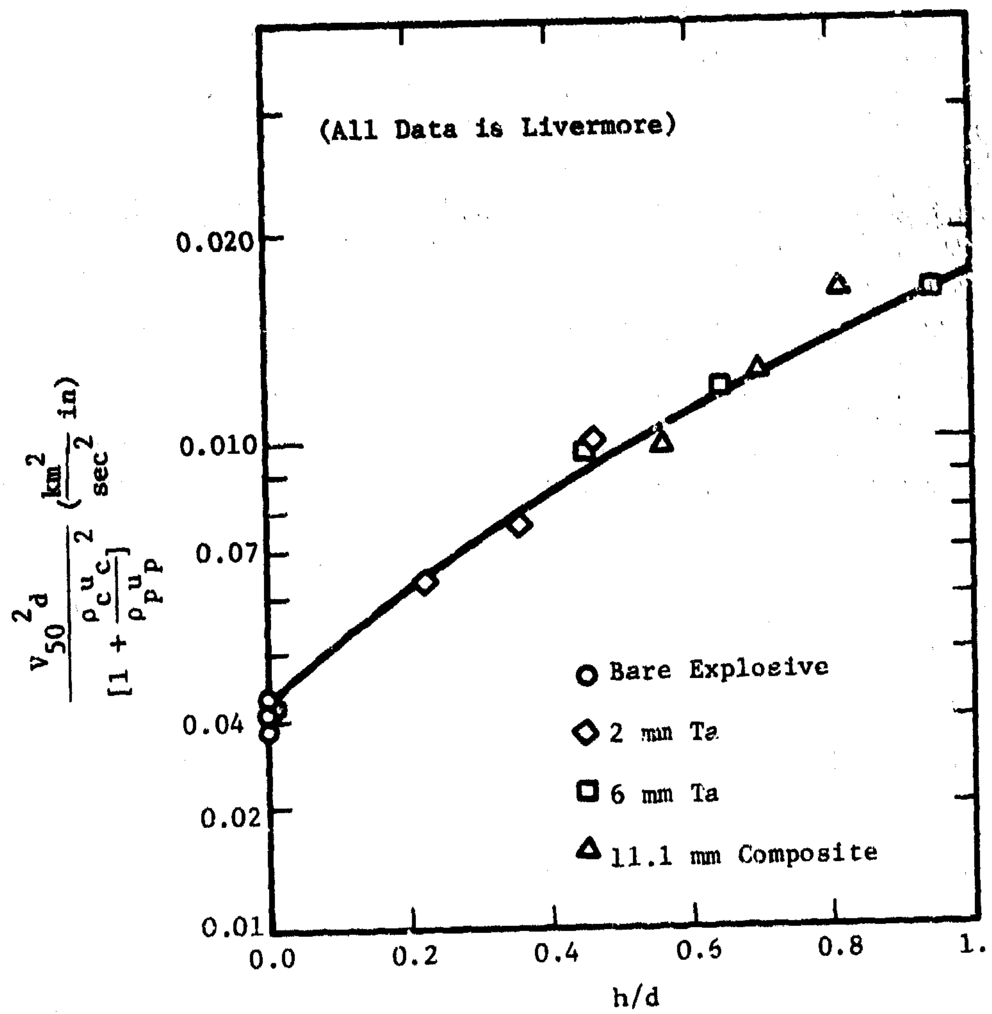


FIGURE 6. SHOCK INITIATION OF PBX-9404

$$SE = \tau(\pi d)(h)(h/2) = (\pi/2)\tau dh^2 \tag{17}$$

Equating Equations (16) and (17) and rearranging terms gives:

$$\left(\frac{h}{d}\right)^2 = \frac{V_{50}{}^2 \rho_p \ell}{4\tau d} \tag{18}$$

In order to plot Equation (18) in Figure 1 so it could be compared with the shock initiation threshold, it had to be transformed by multiplying both sides by $4\tau d^2 \rho_e{}^2 u_e{}^2/\rho_p \ell A_o$. The resulting equation is given by:

$$\left[\frac{dV_{50}{}^2}{\left(\dfrac{A_o}{\rho_e{}^2 u_e{}^2}\right)}\right] = 4\left[\frac{\tau d^2}{\rho_p \ell\left(\dfrac{A_o}{\rho_e{}^2 u_e{}^2}\right)}\right]\left[\frac{h}{d}\right]^2 \tag{19}$$

Equation (19) was plotted in Figure 1 as a series of dashed lines for constant values of $\tau d^2/[\rho_p \ell(A_o/\rho_e{}^2 u_e{}^2)]$. Theoretically, an explosive should initiate for a given value of h/d in Figure 1, according to whichever initiation threshold curve is first encountered as scaled impact velocities are increased.

COMPARISON WITH CASING PENETRATION TEST RESULTS

Howe (Ref. 1) at BRL makes many comparisons with test results in the casing penetration domain. In making these comparisons, he prefers to define a fineness ratio f equal to ℓ/d and substitute m_p and f into Equation (18) in place of d and ℓ. This substitution gives:

$$\left(\frac{V_{50}}{h}\right)^2 m_p{}^{2/3} f^{1/3} = \left[4\pi^{2/3} \frac{\tau}{\rho_p{}^{1/3}}\right] = b^2 \tag{20}$$

where b is a constant, provided τ and ρ_p are constants. For steel fragments fired into steel casings of the same strength, b is a constant and the effects of size of casing and fragment can be evaluated by taking the square root of Equation (20).

$$\left(\frac{V_{50}}{h}\right)(m_p\sqrt{f})^{1/3} = b \tag{21}$$

Figure 7 presents test results obtained by firing right circular cylindrical fragments against Comp B loaded artillery shells. The data plotted

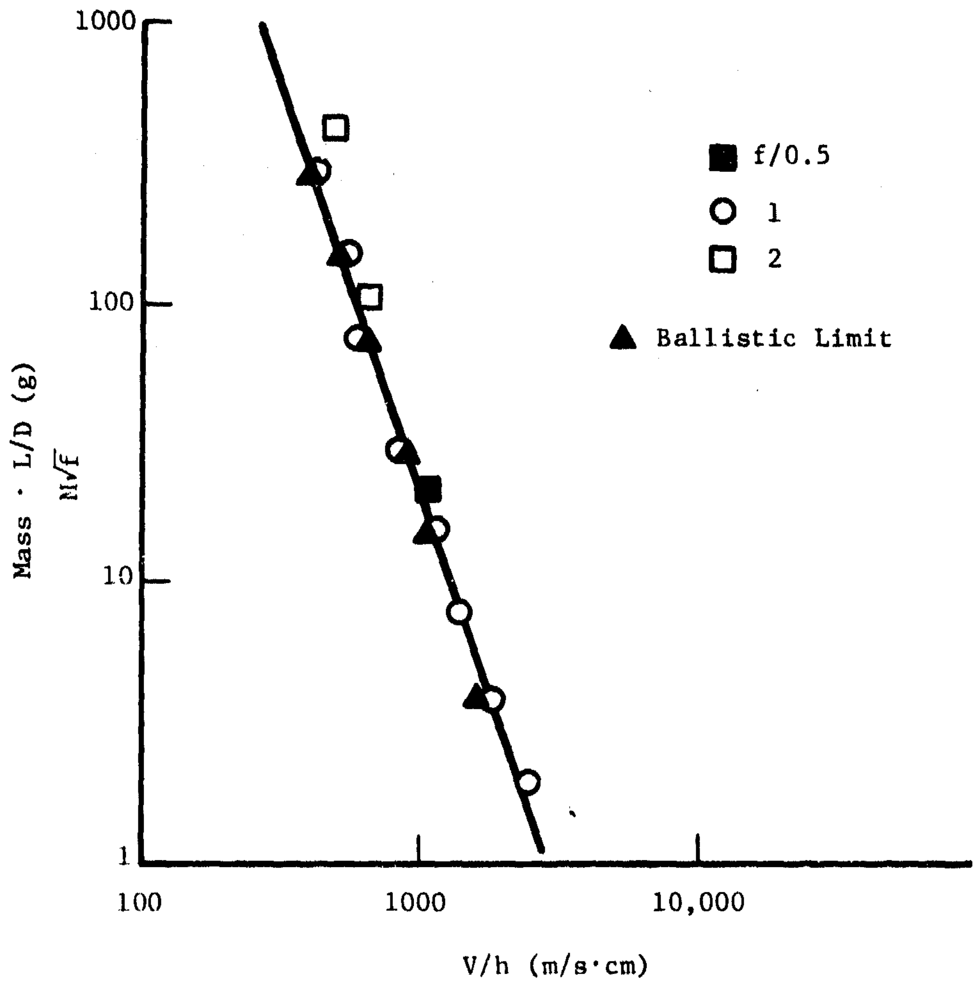


FIGURE 7. CASING PERFORATION INITIATION OF ARTILLERY SHELLS

in this figure are for three different fineness ratios f of 0.5, 1.0, and 2.0. The solid line through the data is a straight line of slope -3 as is predicted by Equation (21). These test results are definitely in the penetration initiation domain and cannot be curve fitted to results in the shock initiation domain which would have a very different slope as should be apparent in Figure 1.

Additional test results were examined for flat impacts of steel cubes against explosive covered with steel plates. This data shown in Figure 8 also has the same slope of minus 1/3 passing through the test results for fragment fineness ratios of 1, 2, and 4. The excellent results further substantiate the existance of this explosive initiation domain.

Finally, Howe has emphasized that results in this domain are independent of explosive or propellant initiation properties by plotting initiation data for a U.S. 5-in. rocket motor and a 122 mm Soviet rocket motor on the same graph as his test results for an artillery shell. The theory in the casing penetration domain assumes that initiation is independent of A_o and other explosive properties. Test results seen in Figure 9 substantiate this conslusion.

FURTHER DISCUSSION

Curvature in the shell casing should have only a minor influence in the casing perforation domain, but in the shock initiation domain, the waves can be focused. Figure 10 compares how waves from flat surface impacts (dashed lines) would propagate into the explosive relative to how waves would propagate from a curved surface (solid line). As can be seen, as one gets deeper into the explosive, the area over which the shock front extends is being reduced. Two added parameter -- (1) curvature of the shell divided by the radius of the penetrator and (2) casing thickness divided by radius of the penetrator -- would have to be added to the solution in the shock initiation domain if impacts into artillery shells were to be studied under these conditions.

Another popular explosive initiation criteria which has been used in the past is the "Put" criteria where the product of impact pressure, peak particle velocity, and duration of loading is assumed to equal to a constant. One can derive the "Put" criteria from Equation (1) provided the slope α on the shock initiation pressure versus distance curve equals 1.0. The slope

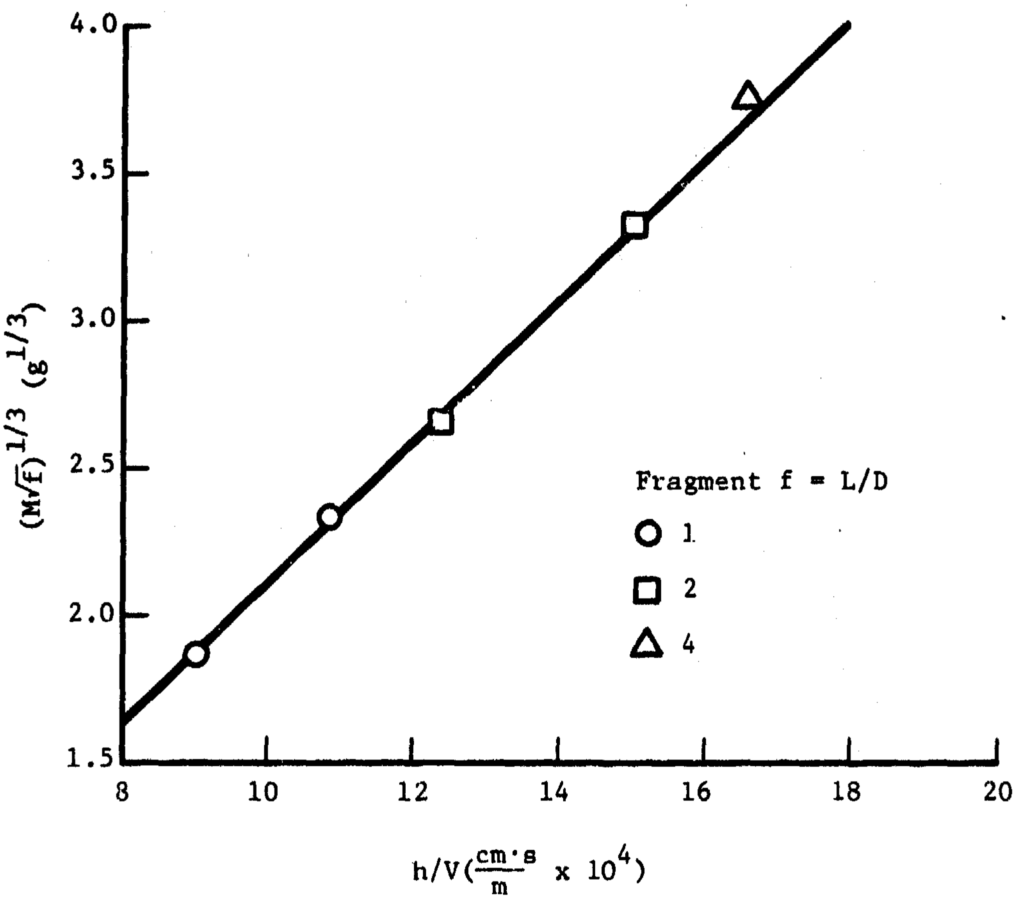


FIGURE 8. CASING PERFORATION INITIATION OF EXPLOSIVE FOR STEEL CUBES THROUGH FLAT PLATES

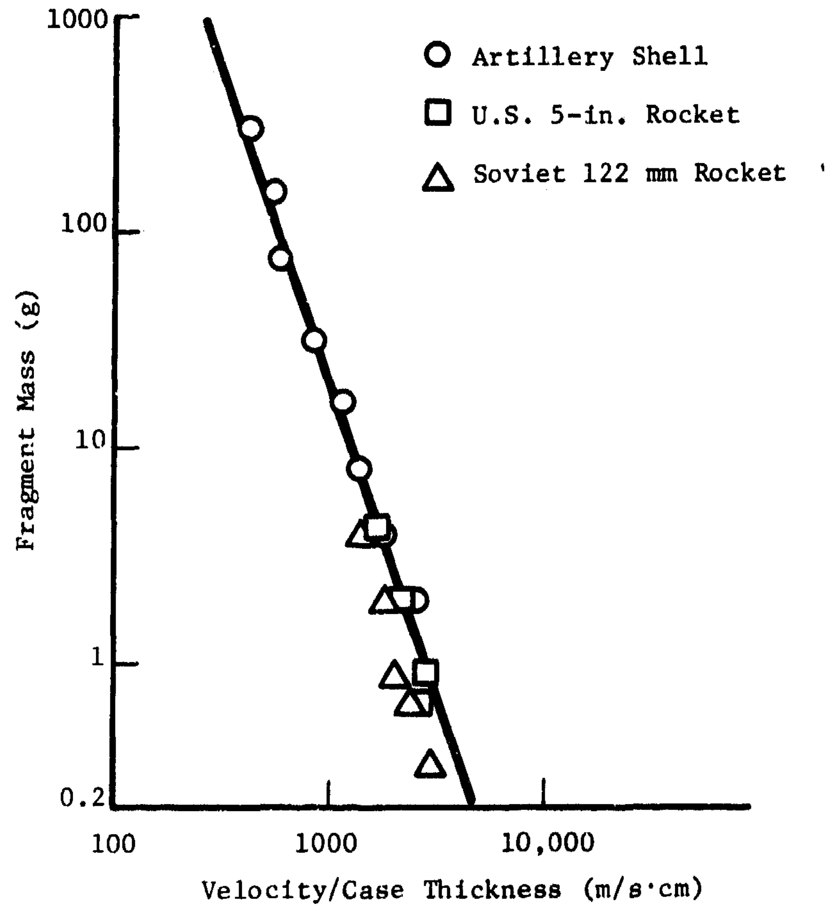


FIGURE 9. COMPARISON OF ROCKET MOTORS WITH ARTILLERY SHELL

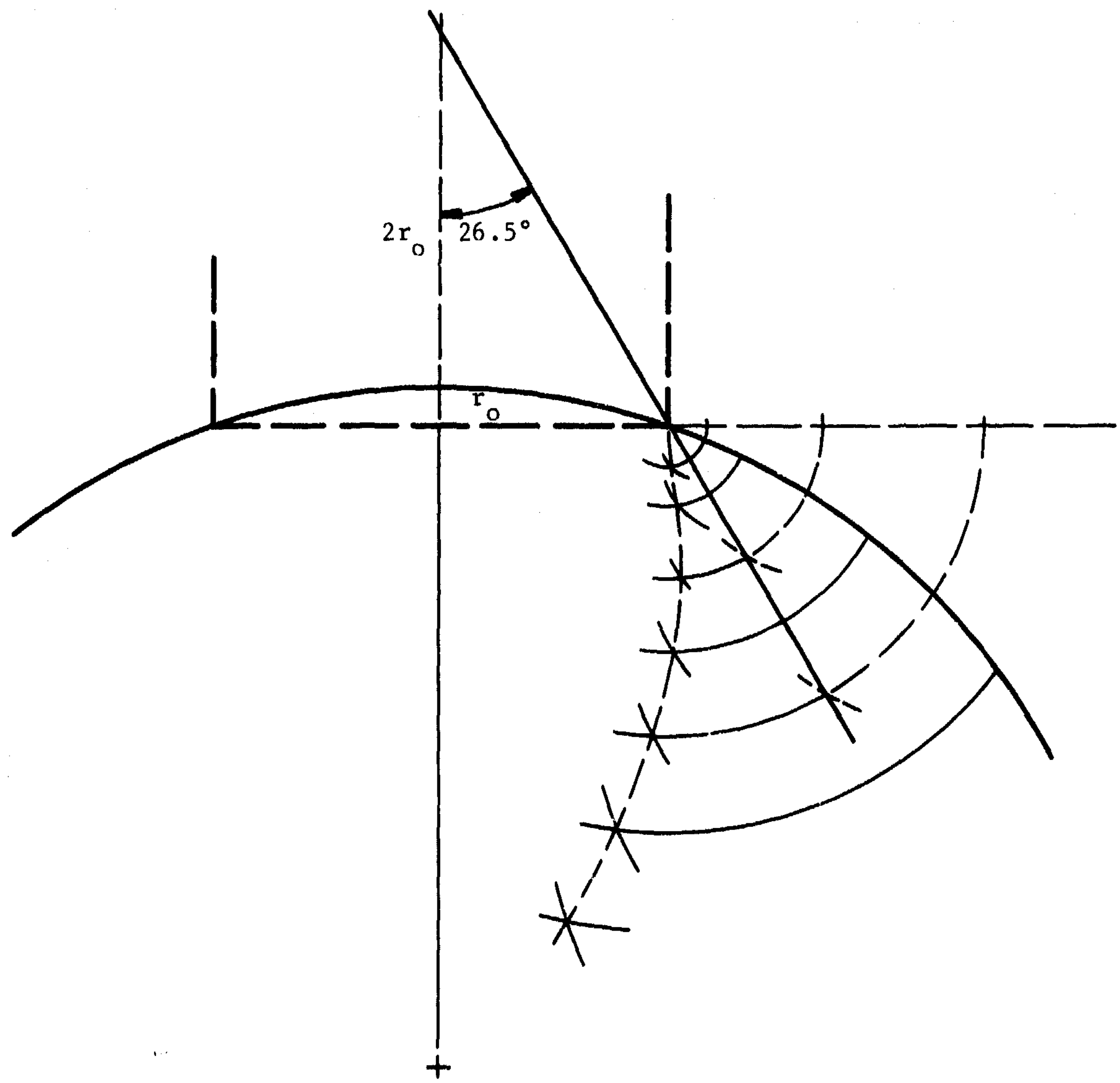


FIGURE 10. QUANTITATIVE INFLUENCE OF CASING CURVATURE ON WAVES PROPAGATED INTO EXPLOSIVE

for the explosives in Figure 2 all range from 1.3 to 3.0 with an average very near 2.0. This observation means that the "Put" criteria which is an energy per unit area criteria does <u>not</u> describe the processes which have been observed in this presentation.

SUMMARY

In this article, the initiation of explosive from fragment impact has been discussed. An uncased explosive initiates because of the high shock pressures which propagate into the explosive; cased explosive can initiate either from shock wave propagation into the explosive or from fragment perforation of the casing. Figure 1 has been developed to graphically demonstrate what combination of conditions are required for initiation by either mode of response. In the shock initiation mode, the threshold of response is a function of a three-parameter space of nondimensional numbers.

$$\frac{V_{50}^{2} d}{\left(\frac{A_o}{\rho_e^{2} u_e^{2}}\right)} = f_{shock}\left(\frac{\rho_c u_c}{\rho_p u_p}, \frac{h}{d}\right) \tag{22}$$

In the perforation domain, the threshold of response is presented graphically as a function of another three-parameter space:

$$\frac{V_{50}^{2} d}{\left(\frac{A_o}{\rho_e^{2} u_e^{2}}\right)} = f_{perforation}\left(\frac{\tau d^{2}}{\rho_p \ell \left(\frac{A_o}{\rho_e^{2} u_e^{2}}\right)}, \frac{h}{d}\right) \tag{23}$$

Various test data taken from the literature and presented in Figures 4 through 9 are used to demonstrate the validity of these observations.

For curved surfaces such as on artillery shells, the three-parameter space presented functionally as Equation (22) is not adequate because waves are focused. Although a quantitative technique is not presented, a qualitative discussion is presented which concludes that two more nondimensional parameters, a nondimensional casing thickness and a nondimensional casing curvature, must be added to correctly predict thresholds for shock wave initiation of explosive when curved surfaces are involved.

This discussion emphasizes that different schools of thought as represented by Livermore and BRL personnel are not inconsistent with one another because each is concentrating on explosive initiation in different domains.

ACKNOWLEDGEMENTS

At SwRI, the writer is indebted to Dr. Wilfred E. Baker, who began the process of nondimensionalizing explosive initiation during a first iteration of looking into this problem for other purposes.

All figures in this paper were drawn by Mr. Victor Hernandez of SwRI and this paper was typed by Mrs. Julie Newman.

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A TECHNIQUE TO REDUCE THE DAMAGE RADIUS
OF PALLETIZED ARTILLERY AMMUNITION

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I. INTRODUCTION

The unfortunate characteristic of mass detonable munitions which separates them from other types of munitions is the fact that, given the detonation of one munition within an array, all, or nearly all, of the other collocated munitions will also detonate. Thus, the size of the resultant explosion is limited only by the number of munitions within the array. As part of the Safe Transport of Munitions (STROM) Program, we have been concerned with devising ways of limiting the size of an explosive event to a small fraction of an array. In this paper, processes by which development of a mass detonation occurs are discussed and some techniques which can be used to control the number of munitions which will participate in the explosions are mentioned. In a companion paper[1], results of full scale tests are presented.

II. THE PROCESSES WHICH LEAD TO A MASS DETONATION AND FACTORS WHICH INFLUENCE THEM

There are a number of distinct ways in which detonation of one munition will cause detonation of nearest neighbors, with resultant explosion of the entire stack. Each of these must be isolated and eliminated if size of the explosion is to be controlled.

A. Classicial Shock Initiation: Introduction of a strong shock wave into an explosive can cause prompt chemical decomposition of the explosive, causing the shock wave to accelerate to a detonation. Classical shock initiation is the process by which initiation of munitions in the design mode occurs; our explosive trains are designed to generate shock waves which will lead to detonation of the main charge. For any given explosive, there exists a set of shock pressures and durations which will lead to

[1] *Collis, D., et al, "Large Scale Tests of Techniques to Reduce Explosion Severity of Mass Detonable Munitions," this proceeding.*

shock initiation. There are several criteria in the literature which permit calculation of these conditions, most notably the "crtical energy" concept of Frank Walker[2] and the Jacobs-Roslund equation[3].

Detonation of a munition can generate shock waves which exceed the initiation threshold in neighboring munitions in either of two ways: (1) For munitions in contact with the detonating source munition, a sufficiently strong shock wave can be transmitted to the acceptor explosive directly through the casings of the respective warheads. Elimination of this mechanism can be accomplished by introducing spacing between the munitions or by using an insensitive explosive. Since the initiation process depends both upon peak pressure and duration, and the duration of the shock wave is proportional to the size of the source munition, the larger the munition, the less sensitive the explosive must be. (2) For munitions not in contact with the detonating source munition, impact of casing fragments and explosive products can cause shock initiation. The explosive products, because of their low density (and resulting low shock impedance) are less efficient than the casing fragments in delivering strong shocks to the acceptor explosive, and will cause initiation only for small separations between source and acceptor. For example, tests with 6 lb bare cylindrical explosive donors demonstrated that the bare charges were unable to detonate 105 mm M1 projectiles at separations as small as 4 cm.

The design of most munitions, such as artillery shell, is such that casing fragment impacts are sufficiently violent to cause shock initiation. We are currently developing the computational techniques to predict, for new explosives, the conditions under which shock initiation will <u>not</u> cause round to round communication.

B. Fragment Impact: Although high velocity fragments can generate shock waves which will cause shock initiation, experiments have shown that most munitions are vulnerable to impacts far less severe. Indeed, the dominant mechanism of initiation of heavily confined charges such as artillery shell and bombs involves casing failure, and the ignition threshold is essentially coincident with the ballistic limit of the casing[4].

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[2]*Walker, F. and Wasley, R., "Critical Energy for Shock Initiation of Explosives," Explosivstoffe 17, 4, (1969).*

[3]*Frey, R., et al, "The Initiation of Explosive Charges by Projectile Impact," Sixth Symposium (International) on Detonation, San Diego (1976).*

[4]*Howe, P., "The Response of Munitions to Impact," ARBRL-TR-02169 (AD B040230) (1979).*

Ignitions resulting from fragment impact do not necessarily cause detonation of the impacted charge. Thus, in single fragment impact firings against the A-3 loaded M393 HEP Warhead, which has a very thin wall, reactions quenched due to pressure relief after ignition. Typically, heavy walled munitions, such as artillery shell, react violently. As long as such reactions are less violent than detonations, round to round propagation is unlikely to occur. A rule of thumb is that detonation of the donor munition is required to insure propagation. An instance where this rule breaks down is when thin skinned munitions are packed in arrays where venting cannot occur and, hence, the neighboring munitions are crushed and ruptured. The exposed explosive can then react within the fire ball, contributing to the total blast output.

Recent results obtained at this laboratory indicate that multiple simultaneous ignitions cause the reaction to build up to detonation. Multiple ignitions can be expected to result from impacts resulting from detonation of nearby munitions. To prevent propagation of detonation, munitions must be protected from multiple impacts by fragments with sufficient energy to perforate the warhead casing.

C. Multiple Source Effects: When more than one munition in a closely packed array is allowed to participate in the explosion of the donor charge, all the mechanisms of communication associated with single munitions are present, but an additional, severe problem arises: the simultaneous, or near-simultaneous, detonation of closely packed munitions creates a high velocity focussed fragment beam in the symmetry plane between the munitions. The fragment velocities of this beam are typically of the order of twice those of fragments from a single munition. Since the beam is collimated, these fragment beams present a very serious threat to other munitions, even over large distances. The nature of the mass focussing can be seen in the radiographs in Figure 1. The penetration capability of this focussed beam is about a factor of three greater than that of fragments from the individual munitions. The fragment beam resulting from simultaneous detonation of two 155 mm shells (TNT loaded) was found to perforate a 10 cm mild steel plate located 30 cm away from the nearest edge of the two munitions.

III. TECHNIQUES TO CONTROL THE SZE OF AN EXPLOSION

The above considerations led to the conclusion that there are three factors which can be exploited to control the size of an explosion of mass-detonable munitions; shielding, spacing, and reconfiguration. The first two factors affect the severity of the stimulus delivered to the neighboring munitions by the fragments and explosive products from the detonating source munition(s). The third factor utilizes the nonisotropy of the munitions to insure that the target munitions are placed in position to receive the weakest possible part of the donor munition threat, and to insure that the target munitions are oriented so that they can offer greatest resistance to the incoming threat.

Some sort of shielding is necessary to protect munitions from lethal source fragments. When multiple munitions serve as the explosion source, the shielding must be adequate to overcome the mass focussing. It is impractical to protect against the focussed fragment beams once they are formed, so we investigated shielding techniques which would reduce the hazards associated with primary fragments and would inhibit formation of the mass focussed beams.

To be effective for multi-munition donors, a shield must eliminate lethal primary fragments, eliminate the mass focussing as a threat, and not serve as a lethal fragment itself. The latter consideration drives attention towards frangible, low density materials and away from steel (steel plates can store enough energy to be lethal sources of initiation, especially by crushing).

Gypsum board was chosen as a shield material because it met the above requirements, as well as being relatively inexpensive, and readily available commercially. It was also chosen on the belief that if sufficient shock energy was absorbed, the water of hydration would be released as steam and could be used as a working fluid. However, recent experiments do not support this hypothesis, and this shielding approach relies solely upon the areal density of material within the fragment paths. Experiments with steel, aluminum, plaster, and water shields with thicknesses adjusted to insure the same areal density, showed essentially no difference in shield effectiveness in eliminating hazardous fragments[5]. Of course, the stronger and denser materials, such as steel, should be avoided because of the ease with which they deliver energy to the acceptor munitions, leading to higher delivered pressures and greater tendencies for detonation.

The effectiveness of this shielding approach relies strongly upon proximity of the shield to the donor munitions. Separation of the shield from the donor projectiles by as much as a projectile caliber seriously degrades shield performance. This degradation results, at least partially, from the lack of structural integrity of shields - which lack is a deliberate and necessary design feature, as stated above. When the shields are placed away from donor munitions, the loading environment essentially consists of many individual fragment impacts. Since the shields have little perforation resistance, it cannot efficiently decrease the velocity of the fragments.

This shielding approach is very effective against primary fragments and against the fragment beams. Indeed, using the gypsum-based wallboard, a 5 cm (2 inch) thick shield is adequate to prevent propagation, by either of these mechanisms, between units of TNT filled 155 mm shell. A 7.6 cm (3 inch) shield is required for the more powerful composition-B filled shell.

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[5]*Gibbons, Gould, Ballistic Research Laboratory, private communication.*

The shields are not at all effective in preventing propagation from unit to unit by means of crushing, and adequate spacing must be maintained between units. As can immediately be ascertained by application of replica scaling analysis, the spacing required is a function of the size of the donor unit, with larger units requiring significantly larger separations.

It is extremely important that adequate spacing be maintained to prevent detonation of the acceptor as a result of crushing. The crushing mechanism operates more slowly than does the projectile impact initiation, and times are long enough for the shielding on the acceptor pallets to deform and move away from the munitions. To be effective, the shields must be in contact with the munitions. Thus, when crushing causes detonation of an acceptor unit, the shields are ineffectual, and all undetonated nearest neighbors of the detonating acceptor unit are subjected to lethal fragment impacts.

The shield concept discussed here has been applied successfully to single and double pallet units. It is most efficiently used in conjunction with reconfiguration as discussed above. Its primary advantage is that it can reduce the inhabited building distance to that for the explosive contained within a shielded unit - a single pallet, for example. No evidence exists to indicate that the fragment hazards are appreciably affected by the shielding, although there presumably is, at least, a slight improvement. This approach has several disadvantages; the additional cost of the shielding, the requirement for spacing between units, the need for additional blocking and bracing.

A schematic drawing of an M107 155 mm shell is shown in Figure 2. In common with most gun launched ammunition, this design has the thinnest casing on the sidewall, with the nose and base providing much more material for protection against incoming fragments. While the sidewall is most vulnerable to fragment attack, it also is the source of the largest number of high velocity, lethal fragments. Thus, when such a munition detonates, the fragments from the sidewall present the greatest threat. Orientation of the pallets such that the munitions are oriented nose to nose and base to base should greatly reduce the tendency for propagation from munition to munition, since the nose-nose and base-base configurations provide at once a less lethal threat and a less vulnerable target.

Tests were conducted with single and multiple pallet units to ascertain what gains were possible. Examination of the data indicate that this approach is very effective in eliminating fragment impact as a propagation mechanism. However, unless adequate spacing is placed between donor and acceptor units, rapid crushing with consequent detonation still occurs.

The combination of nose-nose, base-base orientation and proper spacing between units is very effective in limiting propagation of detonation. For transport on rail, where side exposure of munition laden railcars to other

munitions stores is an occurrence of extremely low probability. This approach appears in itself adequate to prevent propagation within a rail-car or from car to car.

IV. SUMMARY AND CONCLUSIONS

An investigation of the processes by which mass detonations evolve has exposed several important mechanisms which must be defeated if the size of the explosion is to be controlled. It was found that three factors - shielding, spacing, and orientation - can be exploited to limit the size of an explosion. Shielding is necessary to reduce the lethality of primary fragments. It is also necessary to prevent serious mass focussing which results from simultaneous or near-simultaneous detonation of multiple warheads. Spacing is required to provide sufficient venting to prevent rapid structural failure of munitions near the explosion source. Reorientation of munitions within an array permits advantage to be taken of the structural nonisotropy of the munitions, to reduce the severity of the threat and increase structural survivability on a particular axis of the stores.

Figure 1 - X-Radiograph of interaction between two detonating right circular cylinders. Fragmentation in symmetry plane is reminiscent of shaped charge development.

Photo courtesy of
G. Gibbons

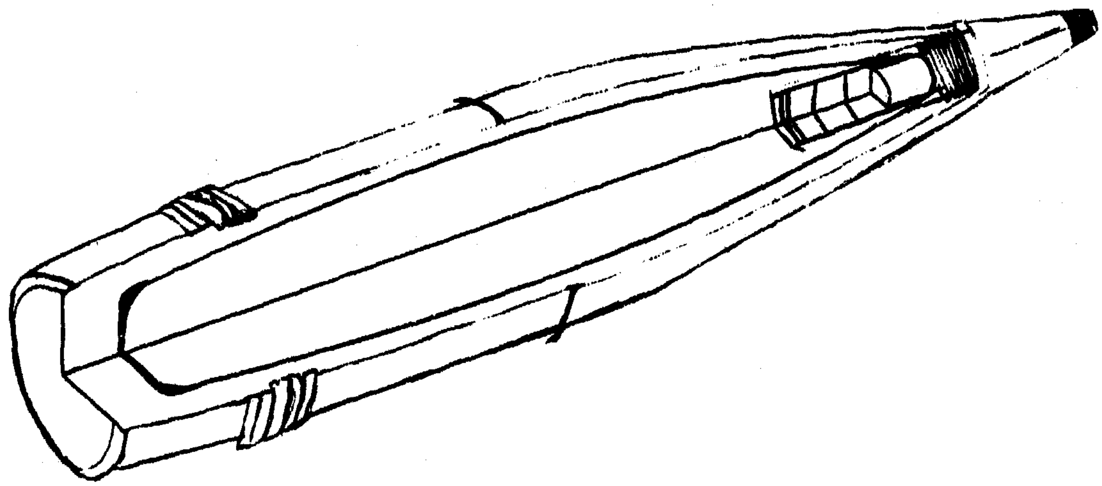

Figure 2 - Schematic drawing of M107 155 mm separate loading projectile. Munition design makes round to round propagation probabilities hightly directional.

METRIC QUANTITY-DISTANCE TABLES BASED ON BLAST IMPULSE

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SUMMARY

American quantity-distance tables utilize a cube root relation and so tacitly assume that the determining factor for blast damage is peak overpressure. A superior damage criterion, however, is blast impulse received within the response time for a target. It has been found that distances from explosions out to a given impulse increase with the 0.55 power of the yield. But at high yields, blast durations are longer than response times for ordinary structures, so that only a portion of the impulse is damaging. Here damage effects follow the conventional 0.33 relation, with the 0.55 relation still pertaining to lower yields.

These quasi-theoretical considerations support the form of the NATO quantity-distance equations, but indicate somewhat different numerical coefficients. Metric tables based on these new coefficients are to be prepared.

BACKGROUND

Distance offers sure protection against damage from explosions. Standard safety distances for inhabited buildings as currently specified[1] when converted into metric units are shown on logarithmic coordinates in Figure 1. Our forthcoming metrication will require that the entire set of these tables be converted into metric units. But conversion is not a simple point-to-point process, for the new tables should show rounded and smoothed increments just as our present ones do. Before constructing such tables, it becomes appropriate to review both the historical and theoretical backgrounds.

Quantity-distance relations for stores of explosives date back to 1909. Values originally suggested for non-barricaded stores[2] are also shown in Figure 1. It can be seen that the original tables have been both

[1] Department of Defense. *DoD Ammunition and Explosives Safety Standards*. Department of Defense (Installations and Logistics), March 1976. (DoD 5154.4S, publication UNCLASSIFIED.)

[2] Ralph Assheton. *History of Explosions*. Wilmington, DE, Institute of Makers of Explosives, 1930.

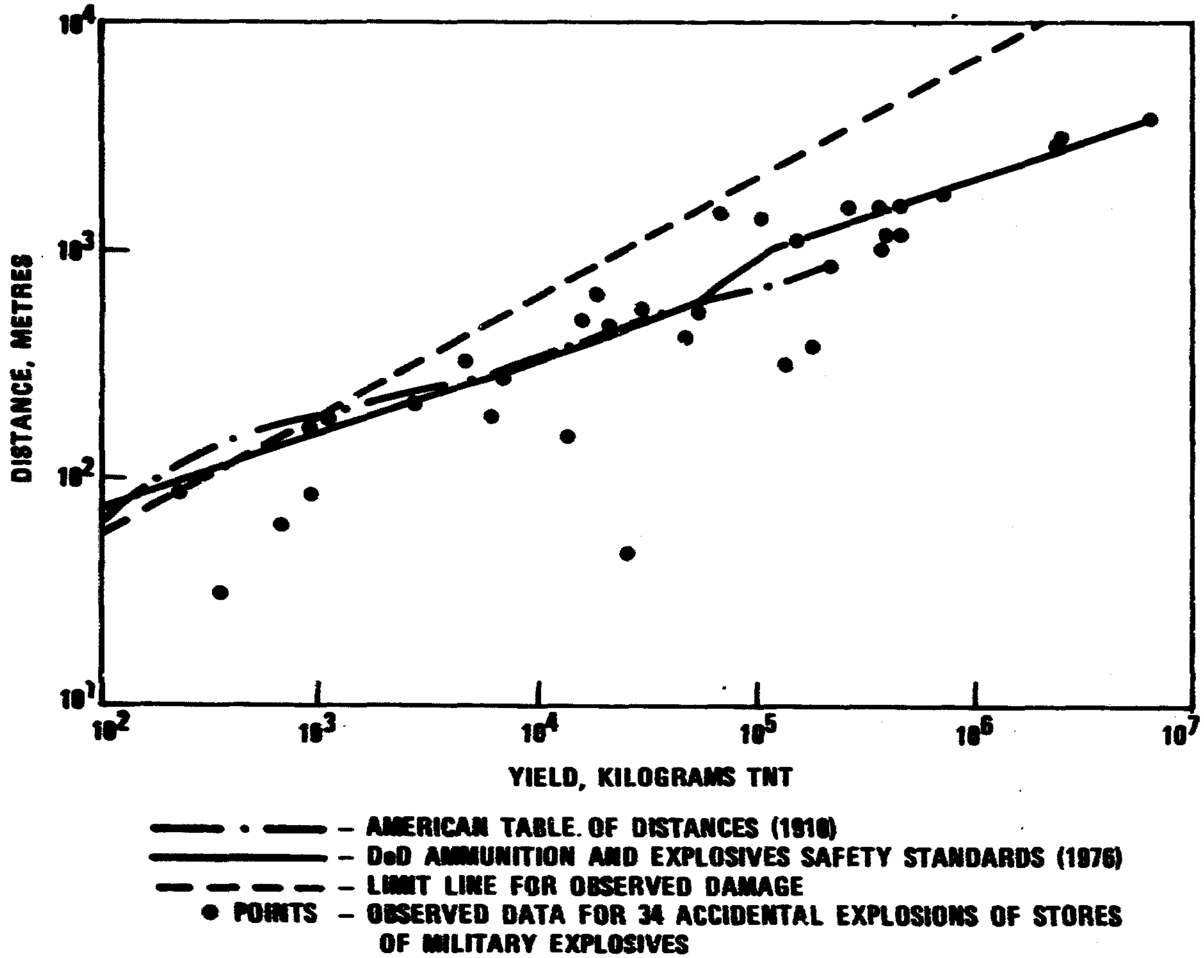

FIGURE 1. Quantity-Distance Relations.

extended and revised. These specified protection distances, as shown by lines in the figure, can be compared with actual distances out to which damage from explosions has been observed. For this, the figure shows points for maximum damage distance for 34 accidental explosions of stores of military explosives as tabulated by Colonel Robinson.[3] Also shown is Robinson's limit line, one that represents quite well actual distance limits for explosions with lesser yields, but which greatly overstates damage distances for very large explosions.

Ideally, damage distances for explosions should not exceed specified protection distances, for this would be wasteful of resources. However, damage effects are determined subjectively, and circumstance of the determination should be taken into account. Thus, there may not have been a structure located at an actual limiting damage distance, so that the observed limiting damage distance understates the needed protection distance. Alternatively, the observed damage might have involved only remotely located flimsy structures that were ready to fall down anyhow, thus indicating a distance greater than actually needed for protection of well-built structures. Furthermore, wind shear and temperature gradients may cause atmospheric focusing with highly localized effects. In spite of such limitations, however, it appears that our current quantity-distance tables are in reasonable accord with limiting damage distances observed for accidental explosions, and so can be quite useful in practical situations.

Protection distances specified in various other quantity-distance tables are shown in Figure 2, all for the special case of inhabited buildings. The curves there include one from the German Accident Prevention Regulations[4] and one based on the NATO tables.[5] They also include a curve for protection distance recommended by the Institute of Makers of Explosives.[6] These latter assume, for smaller explosion yields, protection against missile hazards afforded by revetments, either natural or artificial, if close to a possible target structure. A survey covering various quantity-distance tables is provided by Lyman.[7]

The above curves indicate that all the specified protection distances agree, at least approximately. They also indicate that each shows a slope of about one-third on logarithmic coordinates. Thus, each represents a

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[3] C. S. Robinson. *The Present Status of the American Table of Distances*. Army-Navy Explosives Safety Board, Technical Paper No. 1, July 1945. Publication UNCLASSIFIED.

[4] Rudolf Meyer. *Explosives*. Weinheim, NY, Verlag Chemie, 1977.

[5] Defense Technical Information Center. *NATO Safety Principles for the Storage of Ammunition and Explosives*. Distributed by Defense Technical Information Center, Alexandria, VA. AD 876078 (1969). Publication UNCLASSIFIED.

[6] Institute of Makers of Explosives. *The American Table of Distances*. New York, Inst. of Makers of Explosives, April 1977. (Safety Library Publication Number 2, Publication UNCLASSIFIED.)

[7] Ona R. Lyman. *The History of the Quantity Distance Tables for Explosive Safety*. Aberdeen, MD. Ballistic Research Laboratory, June 1979. (Aberdeen Proving Ground Report ARBRL-MR-02925, Publication UNCLASSIFIED.) AD A072811.

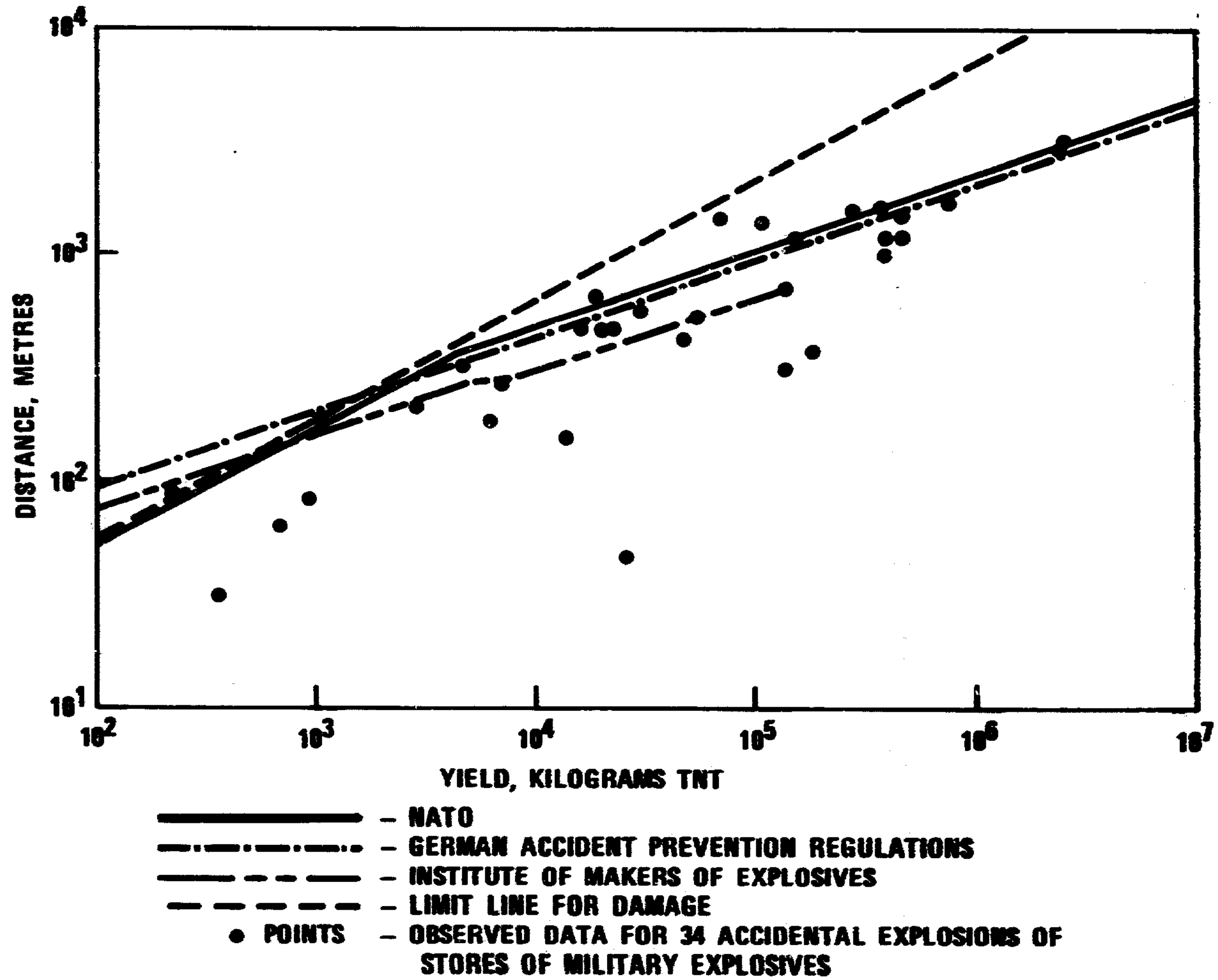

FIGURE 2. Additional Quantity-Distance Relations.

cube root relation between explosion yield and protection distance, or approximately so. It has been shown from theoretical consideration based on the physics of blast waves[8] that the distance out to which an explosion generates a given peak overpressure increases with the cube root of the explosive energy release. Hence it is tacitly assumed that peak overpressure is the determining factor for damage capability of an explosion. This assumption is widely accepted. However, it has recently been shown from elementary mechanics[9] that it is the overpressure-time integral (which also is the blast impulse per unit area) that actually is responsible for target damage, provided that this blast impulse is received within target response time. It was also shown that the distance out to a specified blast impulse, for structures on the ground, increases with the 0.55 power of explosion energy release in explosions on the ground. It can be deduced that safety distances for inhabited buildings increase with the 0.55 power of possible explosion yield, at least for structures with appreciable response times.

For very large explosions, blast wave durations may well exceed response times for typical structures. In this case, only that portion of blast impinging on a target within its response time causes damage. The pressure-time integral for damage then does not include the entire overpressure-time curve, but only its initial portion. The impulse effective in this case becomes approximately proportional to the initial or peak overpressure in the blast. Then, and as indicated above, the distance out to a given damage capability increases with the cube root of explosion yield. Thus, distances specified for protection against damage from large explosions should increase with the cube root of possible explosion yield.

SUGGESTED APPROACH

The above theoretical considerations indicate that distance required for protection against damage by an accidental explosion of a store of explosives is directly proportional to the possible yield when raised to some power, a power whose value is 0.55 for smaller stores of explosives and 1/3 for larger ones. It still remains, however, to establish values for the required constants of proportionality. For this, both judgment and compromise are required. Thus, too large a constant would specify unnecessarily great distances that would be wasteful of both space and resources. Alternatively, too small a constant would specify inadequate distances for proper protection and so give an increased risk of damage.

To obtain optimum values for constants of proportionality in these theoretically deduced quantity-distance relations, we rely on the accumulated experience on which conventional quantity-distance tables are based,

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[8] Gilbert Ford Kinney. *Explosive Shocks in Air*. New York, MacMillan, 1962.

[9] Robert G. S. Sewell and G. F. Kinney. "Response of Structures to Blast; a New Criterion," *Annals of the New York Academy of Science*, Vol. 152 (October 1968), pp. 532-547.

plus factual observations on damage distances. Now for lesser yields the exponent deduced here is 0.55, and this agrees rather well with the value 1/2 used in the NATO expression for lesser yields. It also agrees quite well with the exponent 0.524 in an equation for the Robinson limit line as shown in the above figures. In addition, the distances specified by the NATO equation and the Robinson limit line also agree rather well for lesser explosion yields. Therefore we can evaluate the required constant from a value representative of both relations. This constant so becomes, in metric units, 4.0 metres per kilogram TNT raised to the 0.55 power.

In the higher yield range, the exponent deduced for the quantity-distance relation is 1/3. This is in agreement with many portions of the various quantity-distance relations described above. Moreover these relations all indicate about the same protection distance from specified (larger) stores of explosives. The required constant of proportionality is readily selected from a representative quantity-distance value and is found to be about 20 metres per kilogram TNT raised to the 1/3 power.

Each of the two quantity-distance relations deduced above pertains to only a limited range of explosion yields, but there is a transition between these two ranges where the two relations show identical values. This is at a yield of 1683 kilograms TNT (1.683 metric tonnes TNT) with a distance computed by either relation of 237.9 metres. The complete (rounded) metric quantity-distance relation for stores of explosives is so established. In terms of radial distance R in metres and explosion yield in kilograms TNT, this is

$$R = 4.0\, W^{0.55} \qquad W < 1680 \text{ kg}$$

$$R = 20\, W^{1/3} \qquad W > 1680 \text{ kg}$$

UNITS: R, METRES W, KILOGRAMS

This deduced quantity-distance relation is shown graphically in Figure 3, and there compared with current DOD values[1] and NATO values.[5] All three relations pertain directly only to inhabited buildings. Recommended protection distances for other situations, however, can also be provided by using factors that represent the reduced risk (or increased acceptable risk)

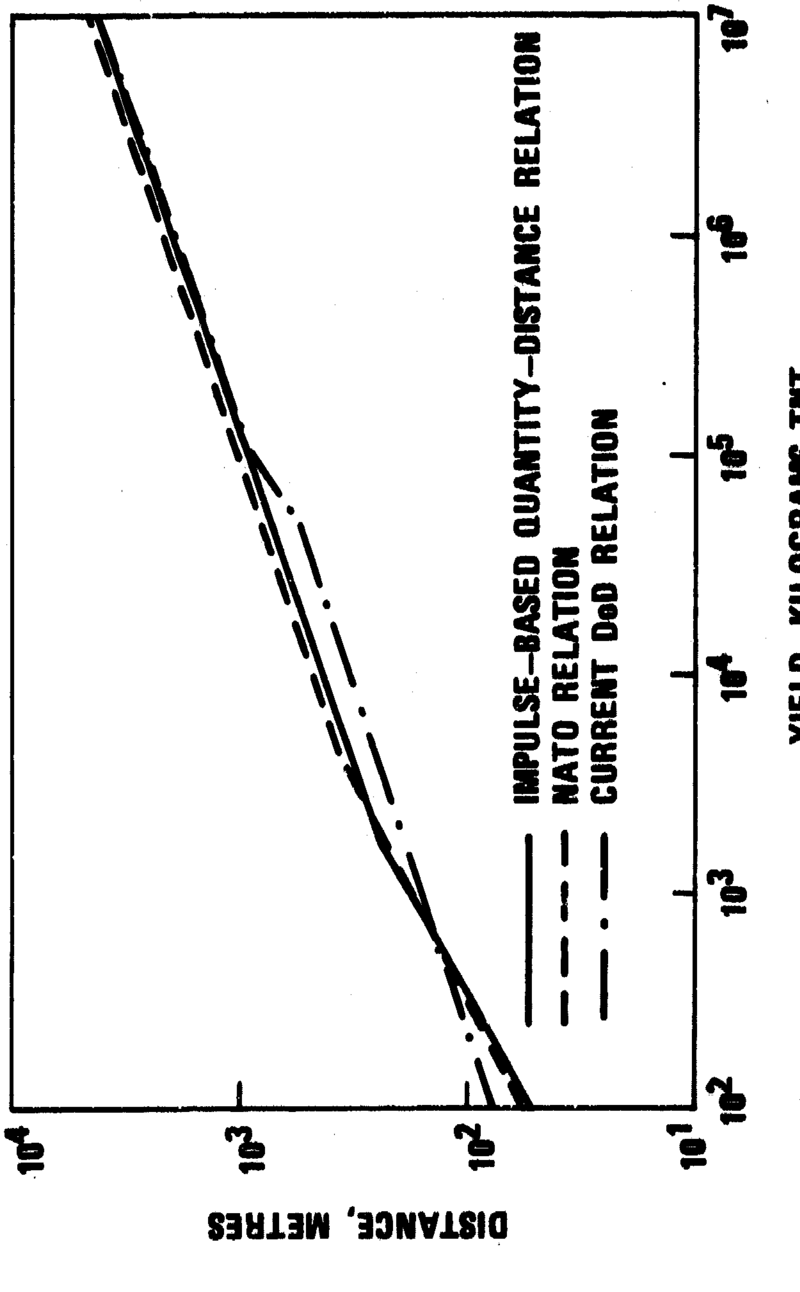

FIGURE 3. Impulse-Based Quantity-Distance Relation.

for a particular situation.[10,11] Thus a recommended safety distance to public traffic routes is 60% that for inhabited buildings, reflecting intermittent and hence reduced exposure. Even lesser safety distances pertain to situations such as the recommended separation between units of a munitions manufacturing plant (the Intraline Distances) because here a somewhat greater risk is considered acceptable. Analogous considerations apply to ammunition depots, etc. Table 1 lists representative factors as given in DoD safety standards.[1]

TABLE 1. Separation Distance Factors for Stores of Explosives.

SITUATION	RATIO TO INHABITED BUILDING DISTANCE
INHABITED BUILDINGS, AIRCRAFT PARKING AREAS, ETC	1.00
PUBLIC TRAFFIC ROUTES	0.60
BETWEEN OPERATING BUILDINGS (INTRALINE DISTANCES)	0.36
WITH PROTECTIVE BARRICADES	0.18
MAGAZINE SEPARATIONS (SELECTED SITUATIONS)	
STANDARD EARTH COVERED ARCH TYPE MAGAZINES, SIDE BY SIDE	0.025
ABOVE GROUND MAGAZINES, NOT EARTH COVERED	0.22

The transition "point" at 1680 kilograms TNT computed above represents the situation where an increased yield produces blast with a duration longer than response time of a typical target. This transition "point" between lower and higher yields actually occurs over a range of values rather than at a mathematical point, but it is of interest to examine it. For this we use the scaling laws for explosions[8] and data for a reference explosion of 1 kilogram TNT in the unconfined atmosphere.[12]

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10 Naval Weapons Center. *Practical Risk Analysis for Safety Management*, by G. F. Kinney and A. D. Wiruth. China Lake, CA, NWC, June 1976. (NWC Technical Publication 5865, publication UNCLASSIFIED.)

11 K. J. Graham and Gilbert F. Kinney. "A Practical Analysis System for Hazards Control," *J. Safety Research*, Vol. 12, No. 1 (Spring 1980), pp. 13-20.

12 Naval Weapons Center. *Engineering Elements of Explosions*, by G. F. Kinney. China Lake, CA, NWC, November 1968. (NWC Technical Publication 4654, publication UNCLASSIFIED.)

From the scaling laws, the distance from a 1 kilogram TNT free air explosion that corresponds to 238 metres from a 1680 kilogram TNT explosion on the ground is found as $(238)/(2 \times 1680)^{1/3} = 15.8$ m/kg$^{1/3}$, where the factor 2 accounts for the hemispherical nature of explosions on the ground. At this scaled distance the peak overpressure in the blast wave is 60 millibars. This might well cause "failure of glass windows, large and small," but would not be expected to cause structural failure of a well-constructed building.[13] A similar characterization can be expected to apply at the recommended protection distances for other quantities of stored explosives.

Duration of the blast wave at the transition "point" can be obtained from the scaled duration that pertains to the reference explosion at a scaled distance of 15.8 m/kg$^{1/3}$. This is given as 3.8 ms/kg$^{1/3}$, so that the actual duration is found to be $3.8 \times (2 \times 1680)^{1/3} = 57$ milliseconds. This computed duration time corresponding to a transition "point" is to be compared with response times for typical structures.

For well-knit structures it has been deduced[8] and verified by analogue computer studies[14] that their response time to a typical blast wave is about 1/4 their natural period of vibration. It also has been ascertained in connection with earthquake vulnerability studies[15] that the frequency of natural vibration of ordinary one-story and two-story buildings is about 4 hertz. This corresponds to a period of vibration of 250 milliseconds, so that 1/4 of this, or about 62 milliseconds, becomes the estimated response time for ordinary structures. The agreement between the typical response time of 62 milliseconds as computed from engineering measurements on typical structures and the corresponding transition point of 57 milliseconds as computed from explosion theory, is perhaps fortuitous. Nevertheless, it supports the analysis methods of this report and lends confidence in its suggested quantity-distance relations.

CONCLUSIONS

In summary, it is deduced here from theoretical considerations that the protection distances in a quantity-distance relation should increase with the 0.55 power of possible explosion yield for smaller stores of explosives, and with the 1/3 power for larger stores. The required constants of proportionality are then evaluated from accumulated experience and from actual damage distance data, providing the relations

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[13] U.S. Atomic Energy Commission. *The Effects of Nuclear Weapons*, ed. by Samuel Glasstone. Washington, D.C., U.S. Atomic Energy Commission, 1962. Publication UNCLASSIFIED.

[14] Naval Weapons Center. *The Yawing Motion of a Finned Free-Flight Missile Produced by a Side-Thrust Rocket Motor*, by R. J. Stirton. China Lake, CA, NOTS, 1953. (NAVORD Report 2070, publication UNCLASSIFIED.)

[15] University of California. *Earthquake and Blast Effects of Structures*. Berkeley, CA, University of California, Engineering Research Institute, 1952.

$$R = 4.0\ W^{0.55} \qquad \text{for} \qquad W < 1680\ \text{kg}$$

$$R = 20\ W^{1/3} \qquad \text{for} \qquad W > 1680\ \text{kg}$$

for a protection distance R in metres and explosion yield of W kilograms TNT. This relation applies directly to distances for inhabited buildings, but can also be applied to other situations by introducing multiplying factors such as those of Table 1. It is strongly recommended that this relation be made the basis for our forthcoming metric tables.

LARGE SCALE TESTS OF TECHNIQUES TO REDUCE EXPLOSION SEVERITY OF MASS DETONABLE MUNITIONS

DAVID COLLIS

ABSTRACT

Tests were conducted with shielded units of 155mm separate loading projectiles to determine the effectiveness of shielding, spacing, and reorientation in preventing propagation of detonation. Two tests were conducted, with milvans stuffed with shielded 16 round units of projectiles. In each test, mass detonation of the stores was prevented. In the first test, several units other than the donor reacted and contributed to the duration of the blast wave. The second test was reconfigured to correct this problem and, of 448 projectiles in the test, 415 were recovered. These tests clearly demonstrate the potential of this approach in limiting the size of explosions on mass detonable stores such as artillery projectiles.

INTRODUCTION

To address packing and shielding improvements with mass detonable stores of 155mm, H.E. projectiles in milvans, the problems involving propagation of detonation must first be recognized. Through a series of tests, three major problem areas were observed: 1) large P_{50} detonation distance for single projectiles and a large reaction distance for palletized projectiles, 2) "jetting" interaction between projectiles within the palletized munitions, and 3) increased donor size with larger scaled tests.

With the addition of shielding materials and different packing configurations within the milvans, all three problem areas were minimized so as to prevent mass detonation of the 155mm projectiles.

SCOPE OF PRELIMINARY STUDIES

A. Reaction/Detonation Thresholds

The P_{50} response point for 155mm projectiles, given one round detonates, was needed in order to devise specific packing and shielding improvement criteria. See Figure 1. The up-and-down method for small samples, as outlined in the American Statistical Association Journal, June, 1953, was applied to the P_{50} detonation

distance for single projectiles. Fourteen tests were conducted to establish a P_{50} = 55cm detonation distance for single projectiles. Seven tests were conducted to establish a reaction distance for palletized projectiles in excess of 9.0 meters.

B. Interaction between Palletized Munitions

A "jetting" interaction between palletized, 155mm projectiles was observed in witness plates from preliminary tests. The angle for which any single "jet" emerges from the pallet during detonation is variable, dependent entirely on which projectile(s) initially detonates. In the instance where all eight projectiles are detonated simultaneously, the emerging "jet" would be normal to the axis between any two projectiles for a total of eight "jets" per pallet.

C. Scaled Up Tests

With small scale tests, i.e., one projectile on one projectile, or 2 on 1, fragment-initiated detonations in the acceptor projectile array appear to be greater than detonations attributed to overpressure. As the preliminary studies expanded in size to include single and multiple pallet tests, fragment-initiated detonations were secondary to detonations attributed to overpressure due to increased donor size. Fragment-initiated detonations were prevented simply with the addition of shielding materials between individual rounds or pallets. Prevention of detonations from overpressure required both the addition of shielding materials and precise packing configurations.

PACKING/SHIELDING TESTS

A. Preliminary Tests

To establish an optimum packing and shielding configuration, several small scale tests were conducted at the New Mexico Institute of Mining and Technology, TERA. From these tests it was concluded that: 1) there was no need to change the current standard pallet form for packaging 155mm projectiles, 2) the pallets would be arranged in groups or nests, and 3) each nest would be positioned to be base-to-base and nose-to-nose with neighboring nests along the length of the milvan wherever geometry permitted.

Based on these conclusions, several larger scaled tests were conducted to establish the optimum shielding and packing configuration.

1. Eight Pallet Nesting

A test setup for the eight-pallet-nest array is shown in Figure 2. This configuration would accommodate 5 nestings with no shielding for a total of 40 pallets per milvan. Each nesting would be placed in the center-of-width to form five rows along the length of the milvan.

The donor size would be one nest with an H.E. weight equal to 446.8 kg (985-lb), yielding an estimated overpressure of ~7000 psi nose-to-nose, and >10,000 psi base-to-base. The results of these tests showed ~75% survival on the base-to-base acceptor nest and no survival on the nose-to-nose acceptor nest. (A survival is defined as no projectile reaction.)

2. Four Pallet Nesting

A test setup for the four-pallet-nest array is shown in Figure 3. This configuration would accommodate 10 nestings with shielding, for a total of 40 pallets per milvan. The shielding material used was a masonite-gypsum wall board-masonite sandwich, positioned on the projectile sides. The nestings would be placed in the milvan to form two rows along the width and five rows along the length. The donor size would be one nest with an H.E. weight equal to 223.6 kg (493-lb), yielding an estimated overpressure of ~5400 psi side-to-side, ~5100 nose-to-nose, and >10,000 psi base-to-base. Test results indicated that there was no nose-to-nose survival and no side-to-side survival. Further testing with the base-to-base parameter was determined unnecessary. Earlier test results showed high survivability with minimum standoff distances between bases of adjoining pallets.

3. Two Pallet Nesting

A test setup for the two-pallet-nest array is shown in Figure 4. This configuration is similar to the four-pallet-nest array with the exception of a smaller donor size and a slightly thicker shield. The donor size was reduced from the four pallet nest by separating two pallets with a support spacer frame and shielding material, thus giving a donor size of 111.8 kg (246-lb), yielding an estimated overpressure of ~4000 psi side-to-side, ~3800 psi nose-to-nose, and >10,000 psi base-to-base. Indications from test results were that these estimated values may be low due/to secondary H.E. reactions in the acceptor arrays. It was evident that acceptor reactions did occur in the stack containing the donor nest, and in the stack which was directly side-to-side with the donor. Portions of several projectiles were recovered which indicated overpressure conditions may have caused these reactions. See Figure 5.

B. Method I Configuration

The preliminary test results indicated that the two pallet nest assembly would be adequate to prevent detonation propagation within milvan munition stores. Figure 6 shows the final two-pallet-nest load-unit assembly. On the sides, top, and bottom is placed the shielding material: 0.64 cm (0.25-inch) thick masonite, 7.62 (3.0-inch) thick gypsum wall board, and 0.64 (0.25-inch) thick masonite. The weight of the shielding material is 190 kg (420-lb), for a total unit weight equal to 915 kg (2000-lb).

Figure 7 shows a milvan packing arrangement utilizing the two pallet nest (Method I).

C. Full Scale Test - Method I

The final test for this packing and shielding arrangement was conducted at the White Sands Missile Range. Two milvan containers were placed side-by-side and partially filled with munitions. One milvan contained 16 nests (20 nests would be required to fill the milvan). The other milvan contained 10 nests. See Figure 8 for details of the milvan loading. One projectile was detonated from a bottom, inside unit within the 16-nest-array milvan, along the outside wall farthest from the 10-nest-array milvan. Figure 9 shows the test-site setup prior to detonation of the donor stack.

Post-firing observations of the test site indicated that several units other than the donor reacted. High speed film read-out of the event supported some acceptor reaction after the initial donor detonation, thus contributing to the duration of the blast wave. Indications were that a mass detonation was prevented. Thirteen intact projectiles were recovered sustaining minimal damage. Portions of numerous projectile bases and many slab-like fragments were also recovered near the immediate test site. Figure 10 shows the post-firing test site. Figure 11 is a view of portions of the debris recovered from the test.

D. Method II Configuration

Although Method I did prevent mass detonation of the munitions, it did not prevent the duration of the blast wave. Additional tests were therefore conducted to improve the packing arrangement in order to reduce secondary acceptor reactions.

1. Staggered Nest Test Array

Several tests were conducted which implied reducing the number of pallets from 40 per milvan to 32, and staggering the rows along the length in a manner such that no nest is directly side-to-side with any other nest within the milvan. From the earlier tests it was concluded that the milvan wall, with an appropriate liner material, could prevent any reaction from occurring in adjoining

milvans. The basic setup is shown in Figure 12. The results showed that the nests in the staggered row adjacent to the donor could survive, sustaining minimal damage. Figure 13 and 14 show typical projectile damage for this configuration. The acceptor stack directly across from the donor had reactions in the lower nest with no evidence of reaction in the upper nest.

2. Milvan Propagation Tests

Several small scale tests were conducted to determine the optimum liner material for milvan walls which would prevent reaction propagation to adjoining milvans. Polyethylene plastic, 1.27cm (0.5-inch) thick, was chosen as a liner. Figure 15 shows typical side-to-side damage received by a projectile in an adjoining milvan utilizing the plastic liner.

3. Final Configuration

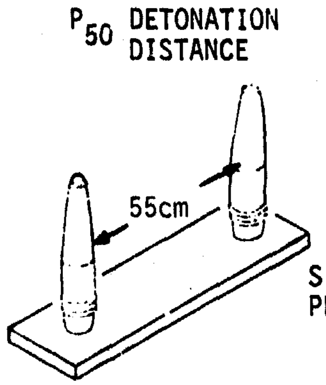
The preliminary tests indicated that the staggered row packing arrangement would minimize reaction/detonation propagation within a milvan and to adjoining milvans. Figure 16 shows a milvan packing arrangement utilizing the two pallet nest in the staggered row configuration (Method II).

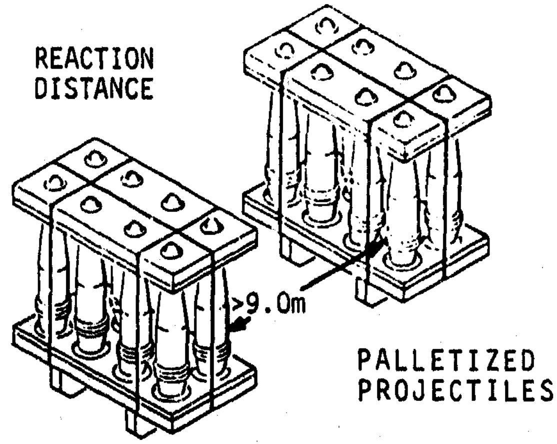
E. Full Scale Test - Method II

The final test for this packing and shielding arrangement was conducted at the White Sands Missile Range. Two milvan containers were placed side-by-side. One container was loaded to capacity (32 pallets); the other was partially loaded (24 pallets). See Figure 17 for details of the milvan loading. One projectile was detonated from the second stack from the end, on the bottom, and on the outside furthest from the partially loaded milvan. Figure 18 shows the test-site setup prior to detonation of the donor stack.

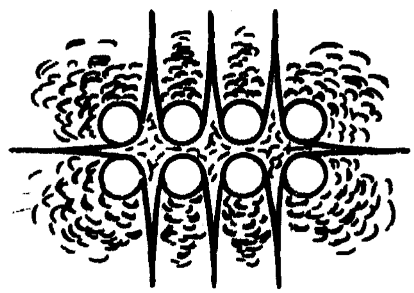
Post-firing observations of the test site indicated that only the donor nest detonated, the acceptor nest above the donor reacted, and no other reactions were evident. Of 448 projectiles in the test, 415 were recovered, most sustaining minimal damage. One nest assembly was partially intact, with several pallet assemblies still intact. Approximately 90% of the debris from the test was recovered inside a 60 meter (200-ft) radius circle. See Figure 19 for a view of the post-firing test-site.

ROUND TO ROUND PROPAGATION

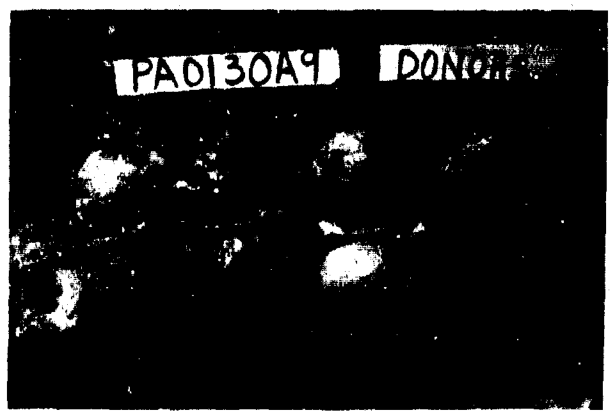




"JETTING" INTERACTION BETWEEN PALLETIZED PROJECTILES



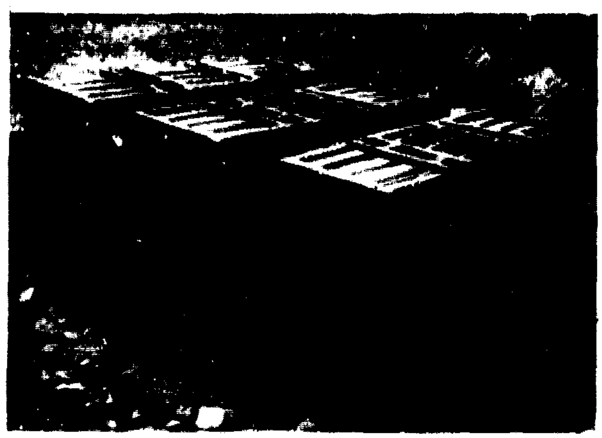
"JETTING" INTERACTION
FOR SIMULTANEOUS
DETONATION



VIEW OF WITNESS PLATE AFTER
MASS DETONATION OF PALLETIZED
PROJECTILES

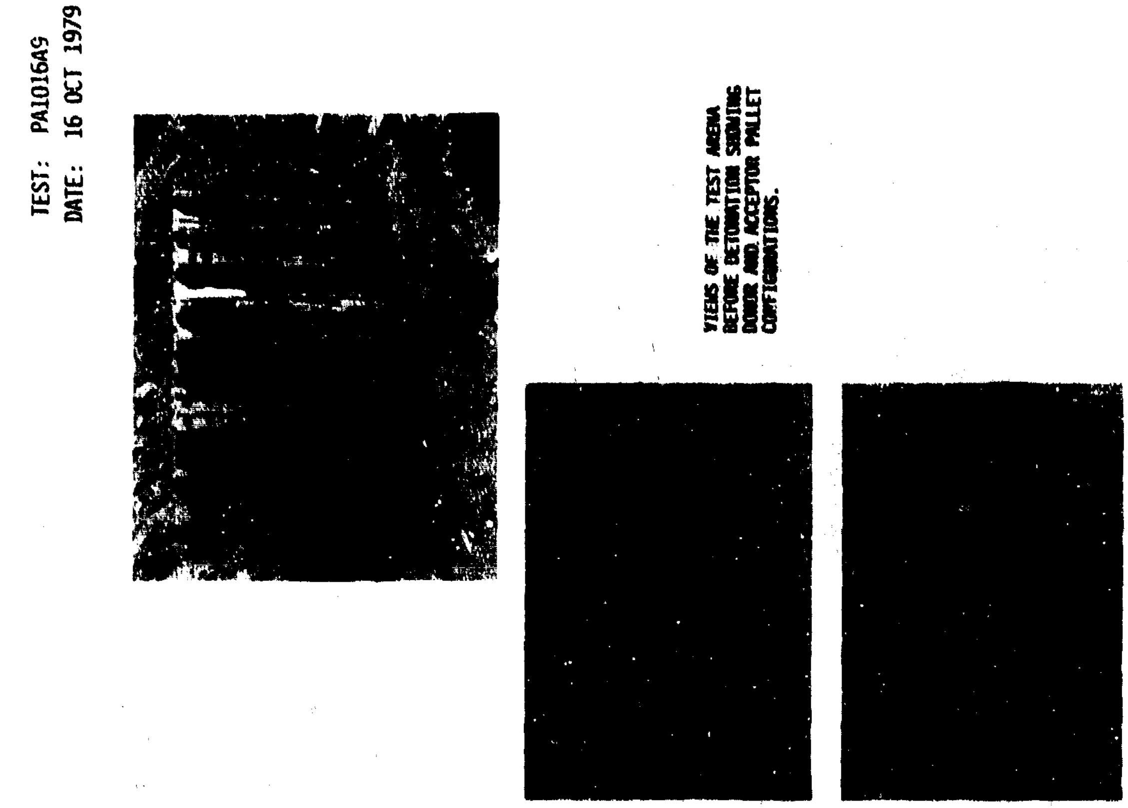
SCALED UP TESTS

SINGLE PROJECTILE TESTS



SINGLE AND MULTIPLE PALLET TESTS

FIGURE 1. MAJOR PROBLEM AREAS



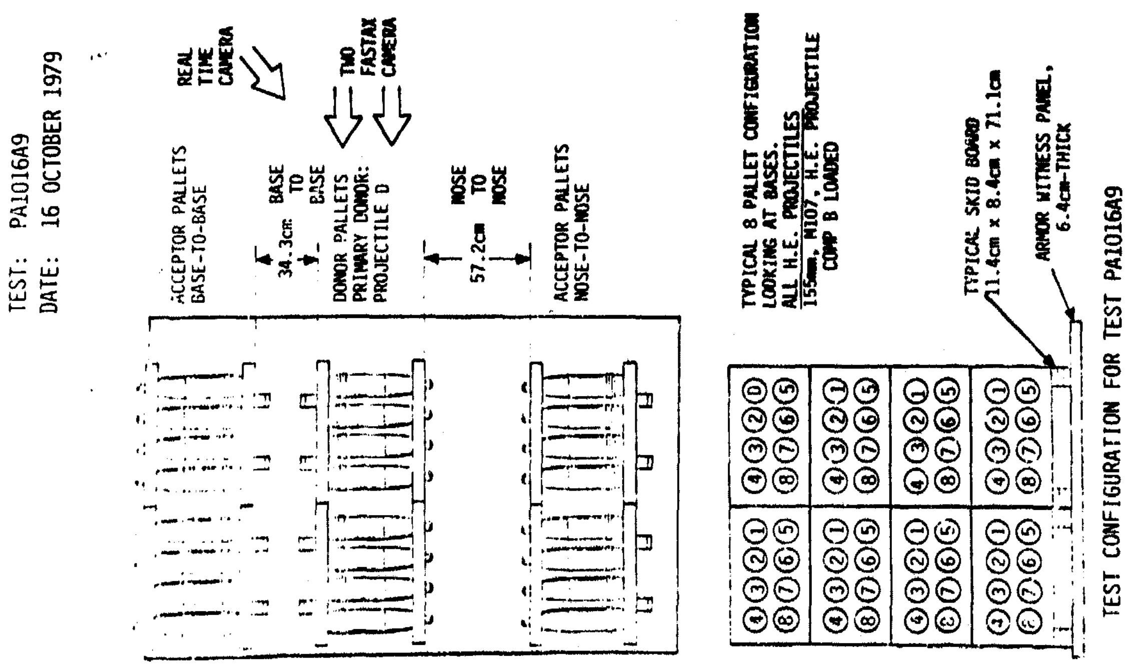
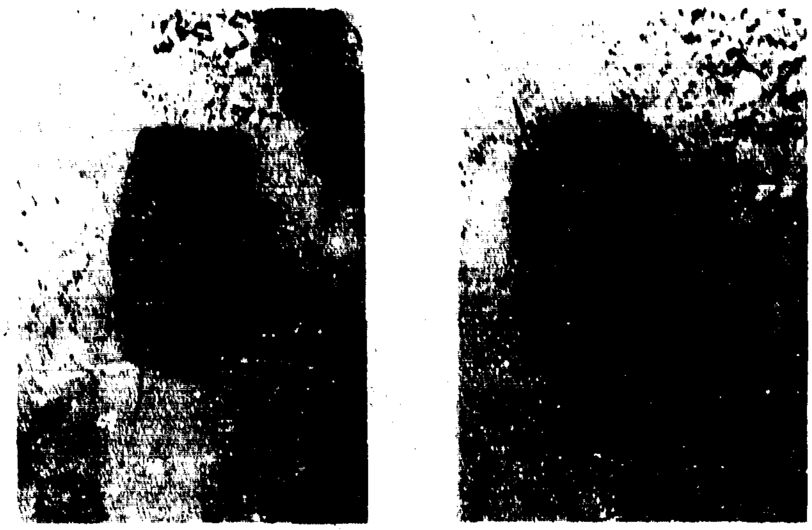
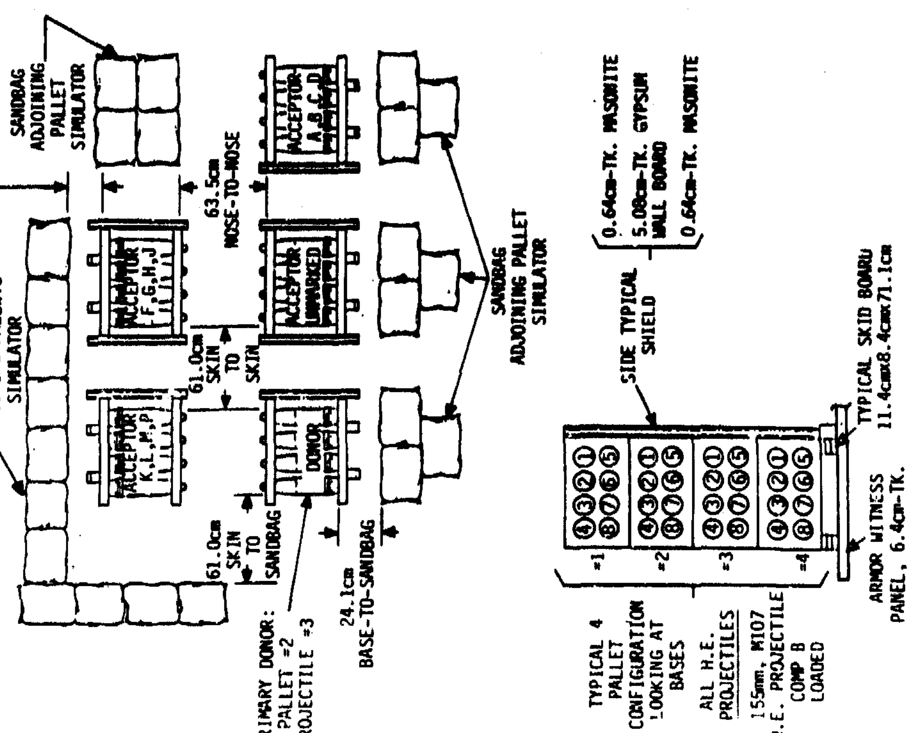


FIGURE 2. TEST SETUP FOR THE EIGHT-PALLET-NEST ARRAY

TEST: PA1210A9
DATE: 10 DECEMBER 1979

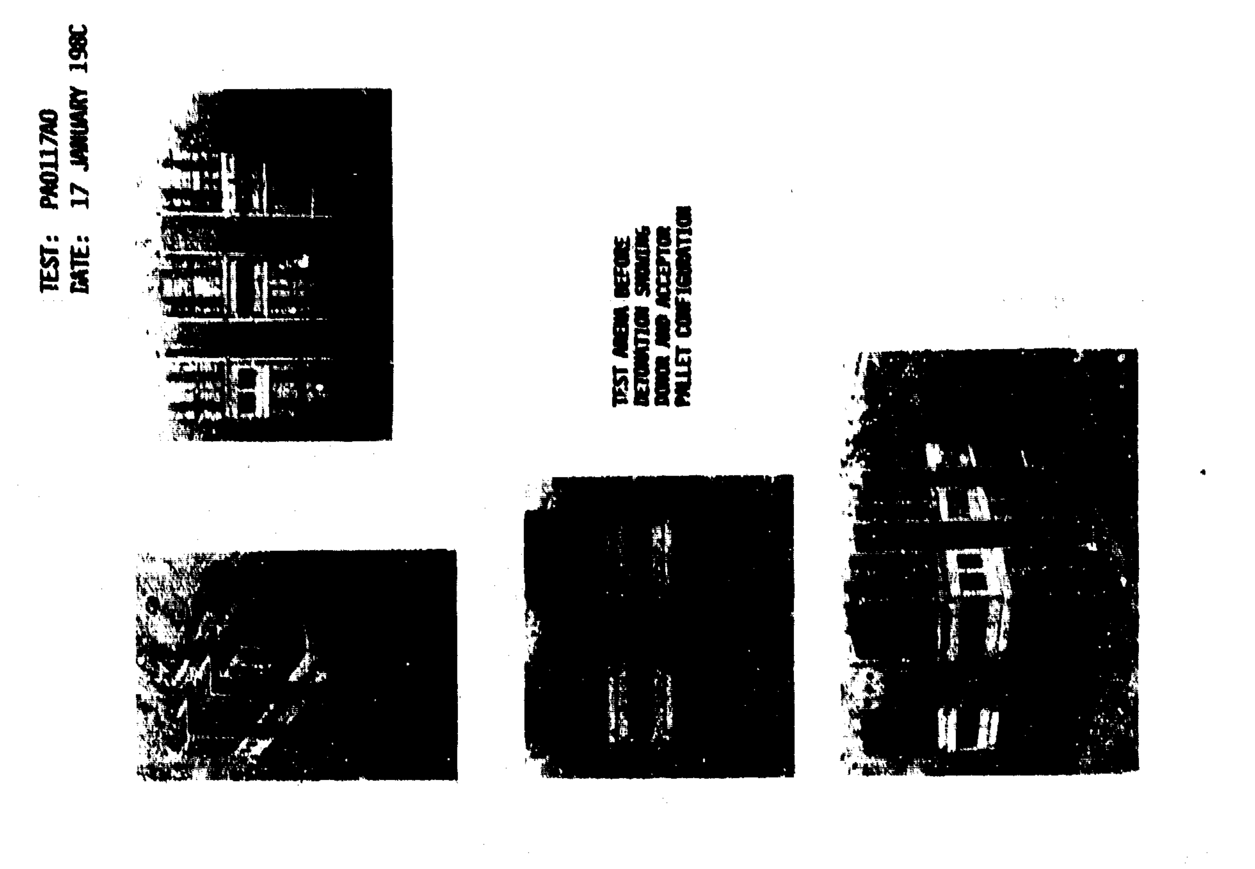


TEST AREA BEFORE DETONATION SHOWING DONOR AND ACCEPTOR PALLET CONFIGURATION



TEST CONFIGURATION FOR TEST PA1210A9

FIGURE 3. TEST SETUP FOR THE FOUR-PALLET-NEST ARRAY



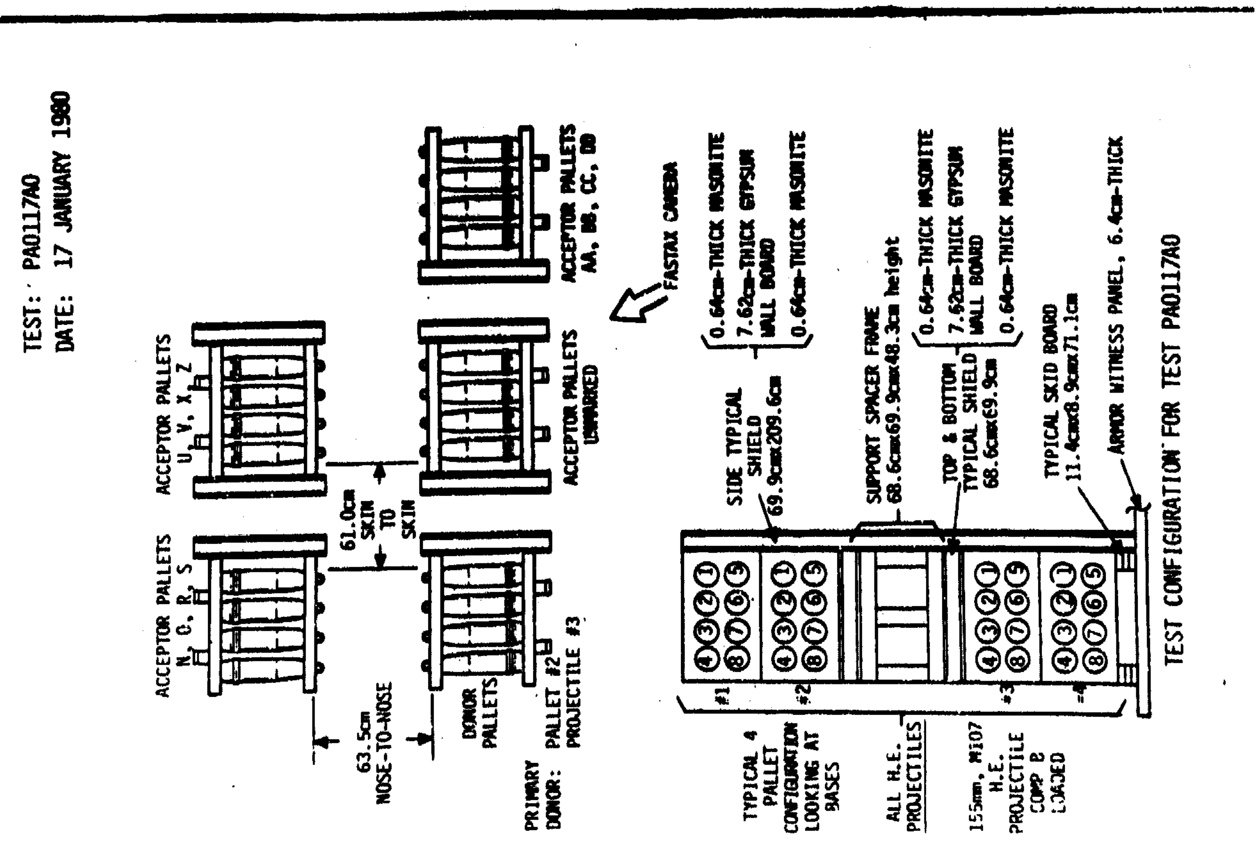


FIGURE 4. TEST SETUP FOR THE TWO-PALLET-NEST ARRAY

FIGURE 5. PORTIONS OF RECOVERED TEST PROJECTILES

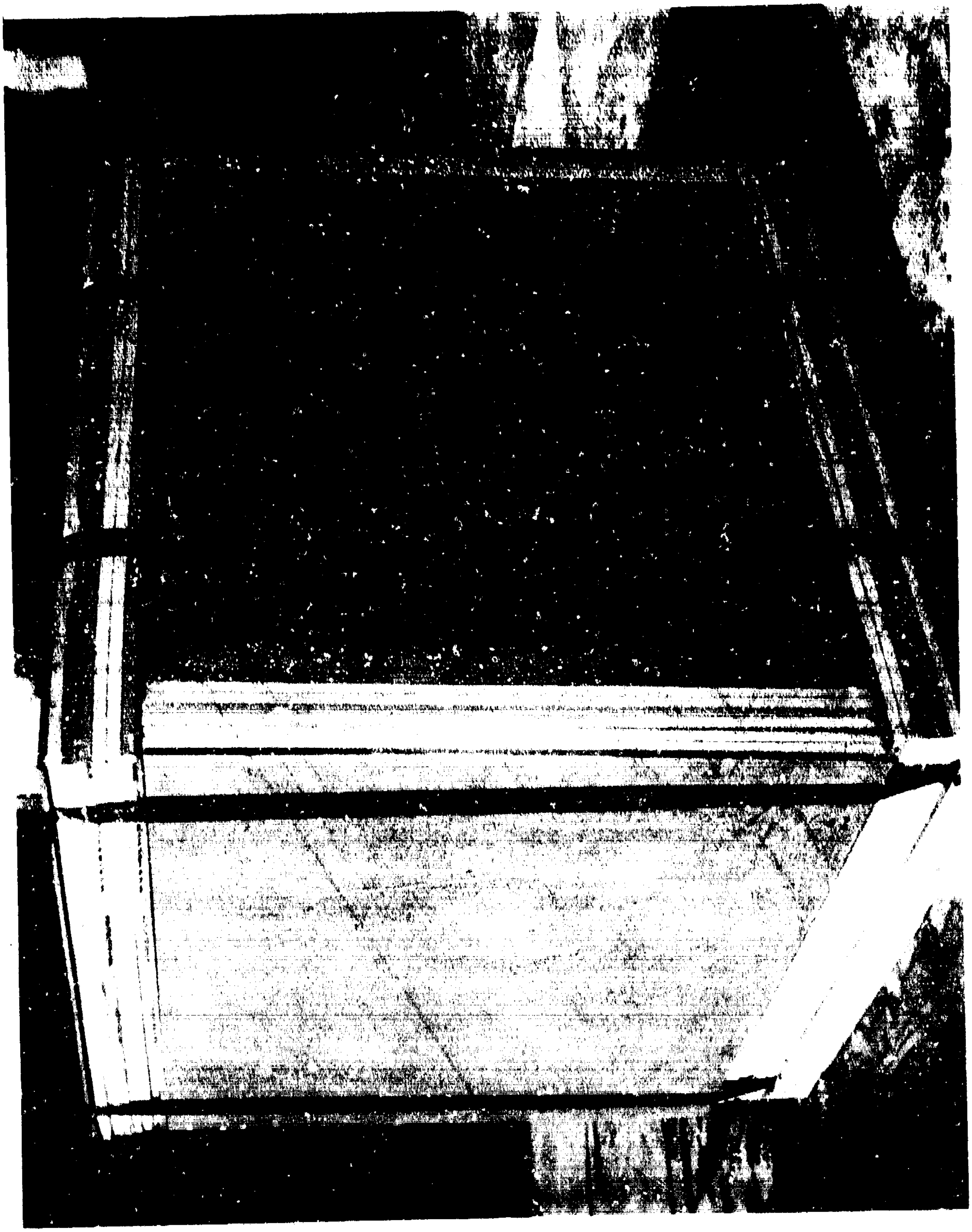


FIGURE 6. TWO-PALLET-NEST LOAD-UNIT ASSEMBLY

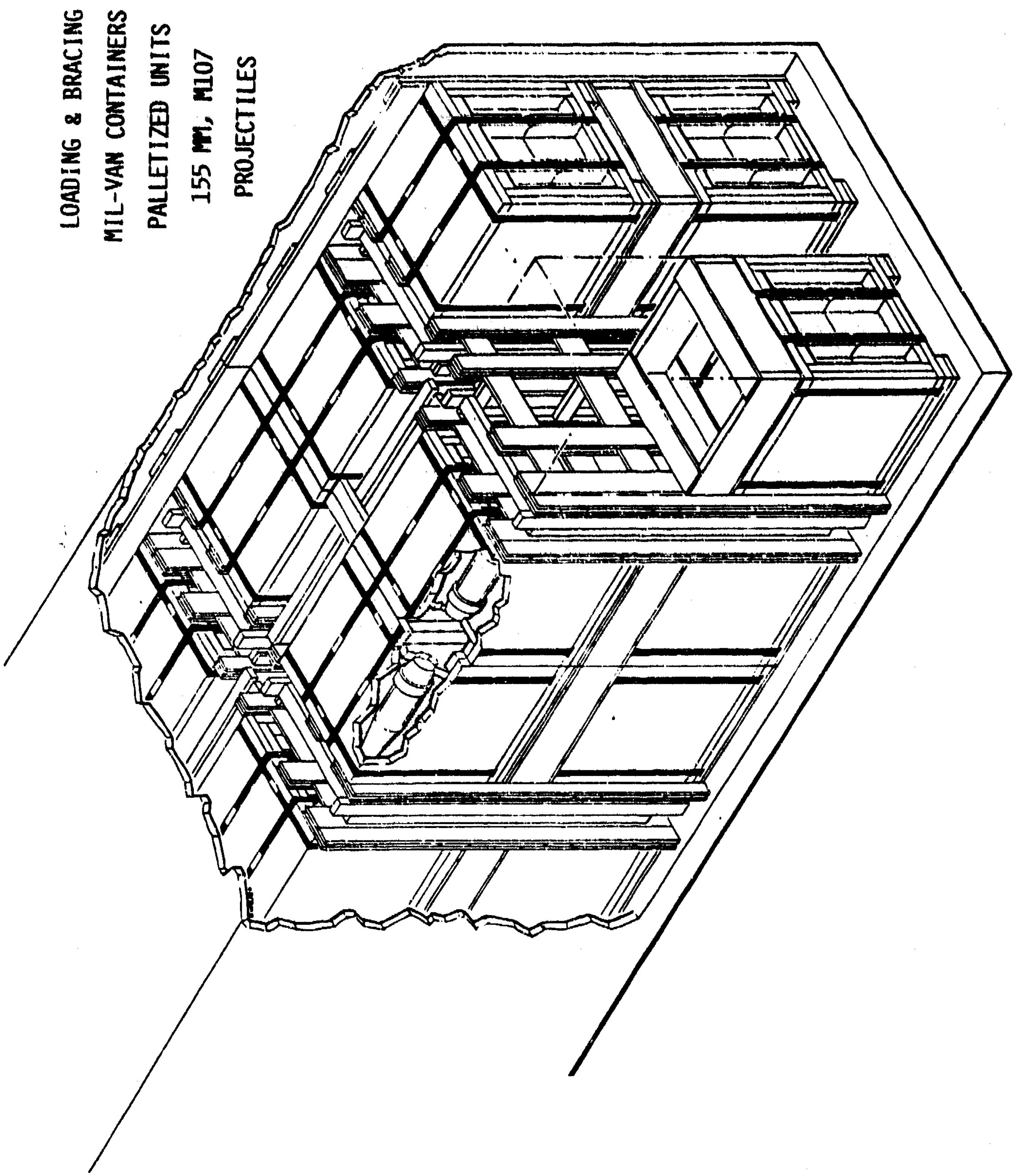


FIGURE 7. MILVAN PACKING ARRANGEMENT - METHOD I

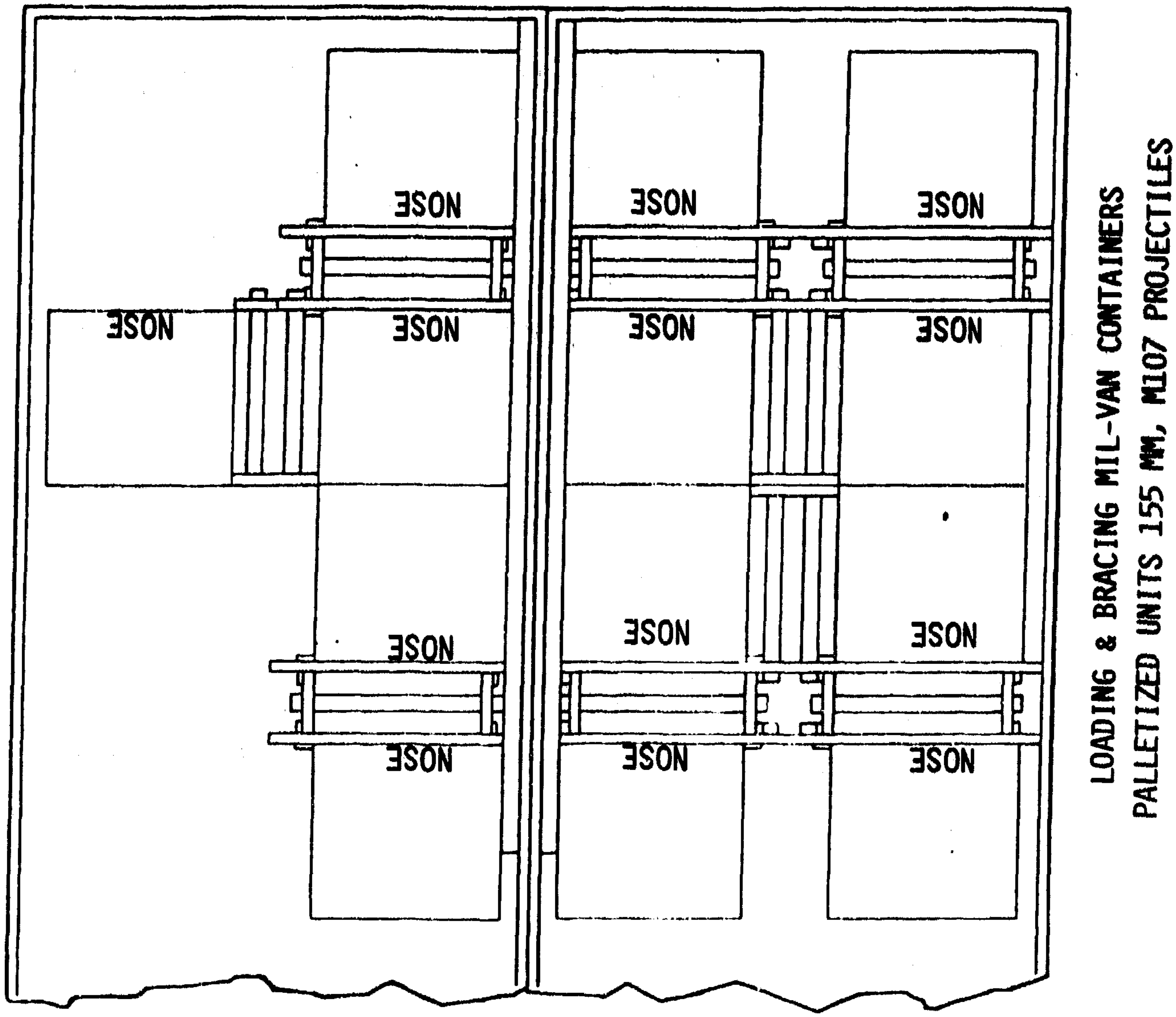


FIGURE 8. MILVAN LOADING - METHOD I

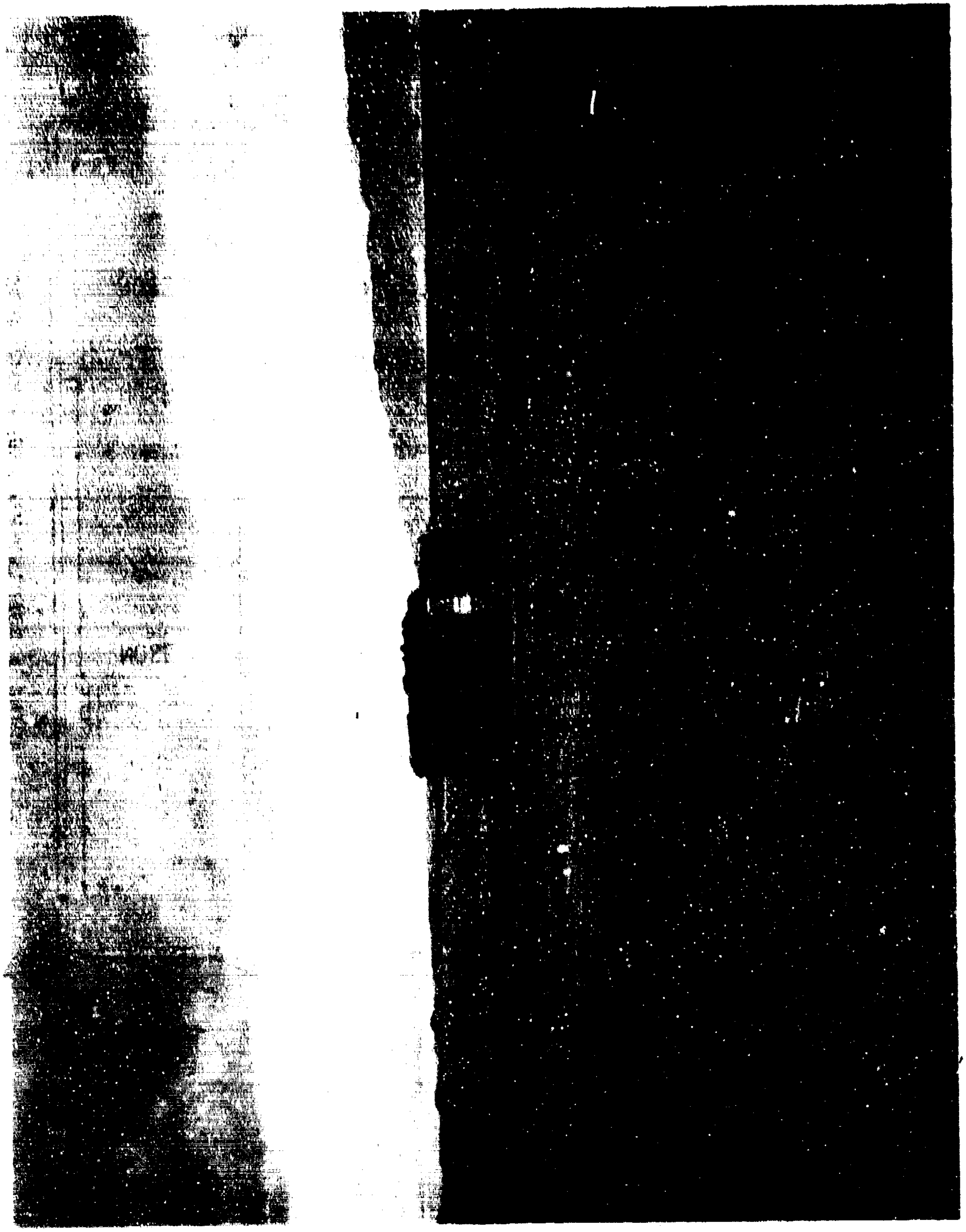


FIGURE 9. TEST SITE SETUP - METHOD I

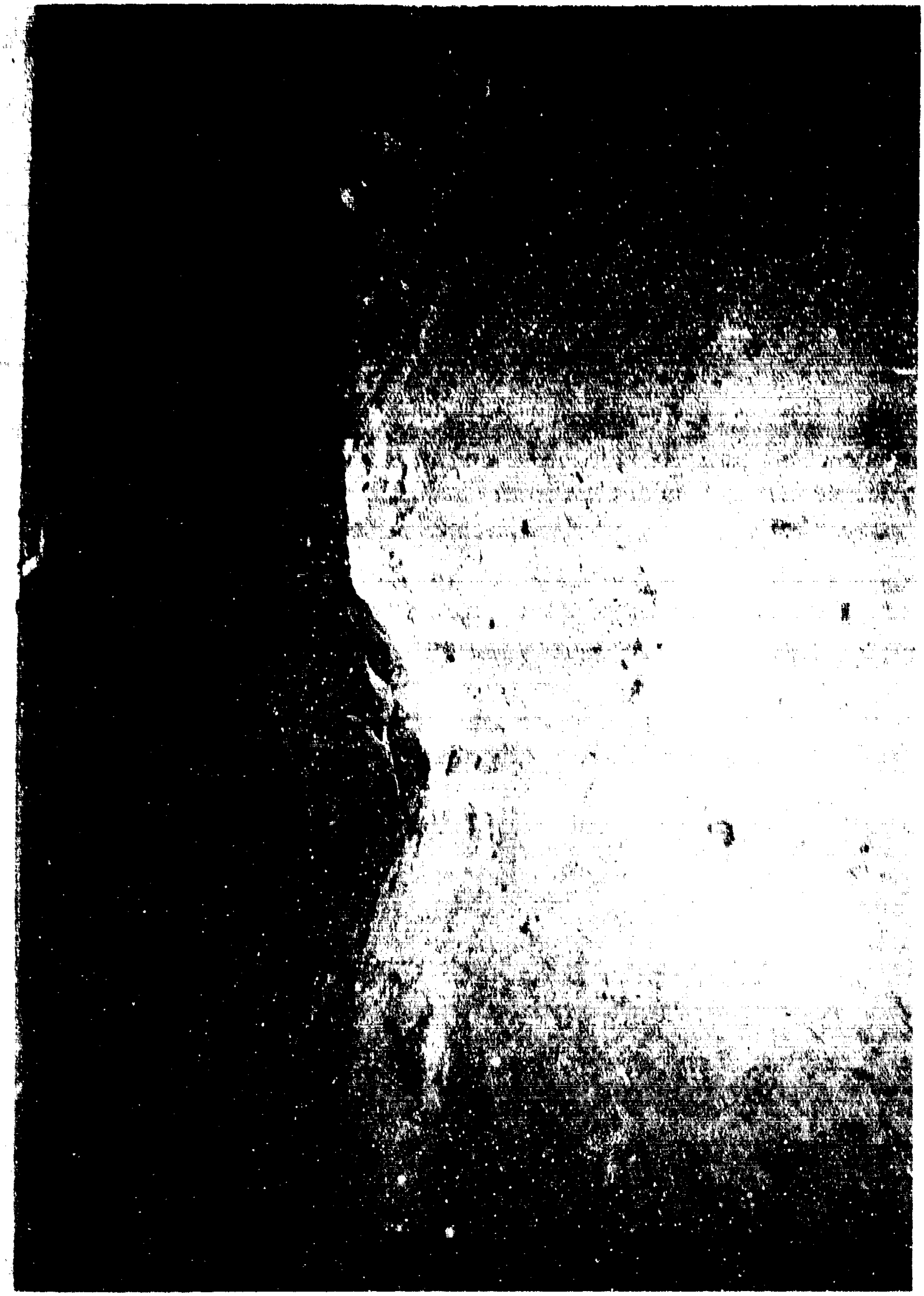
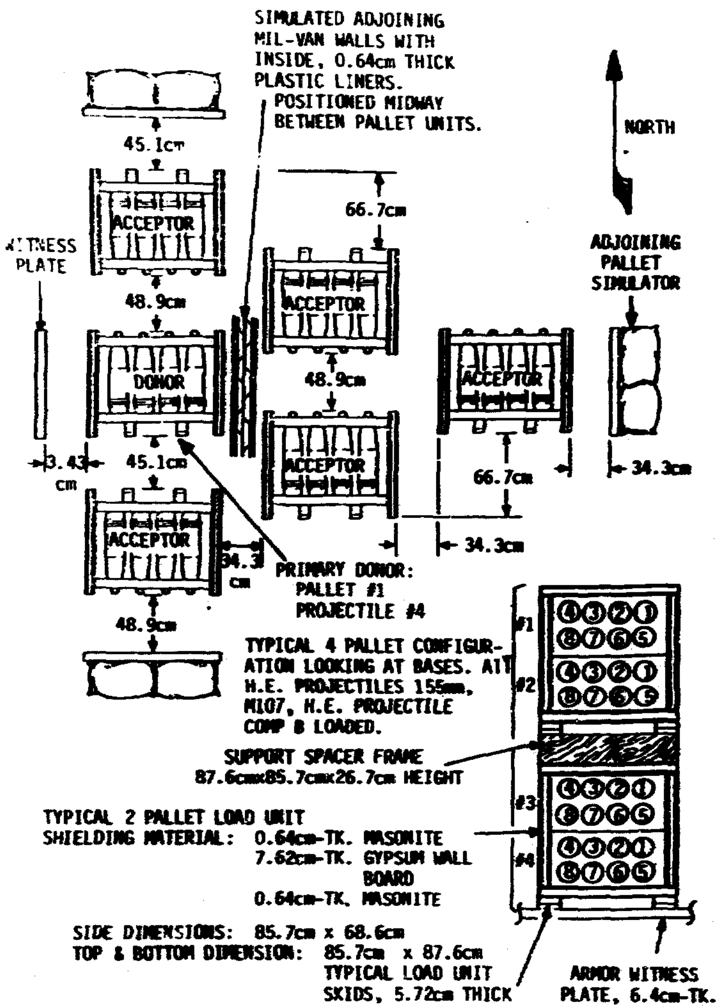


FIGURE 10. POST FIRING TEST SITE - METHOD I

FIGURE 11. RECOVERED DEBRIS FROM TEST - METHOD I

TEST: PA0401A0
DATE: 1 APRIL 1980



TEST CONFIGURATION FOR TEST PA0401A0

OVERALL VIEWS OF TEST SETUP
LOOKING FROM SOUTH TO NORTH

FIGURE 12. STAGGERED NEST TEST ARRAY

FIGURE 13. TYPICAL NOSE DAMAGE - METHOD II

FIGURE 14. TYPICAL BASE DAMAGE - METHOD II

FIGURE 15. TYPICAL SIDE DAMAGE - METHOD II

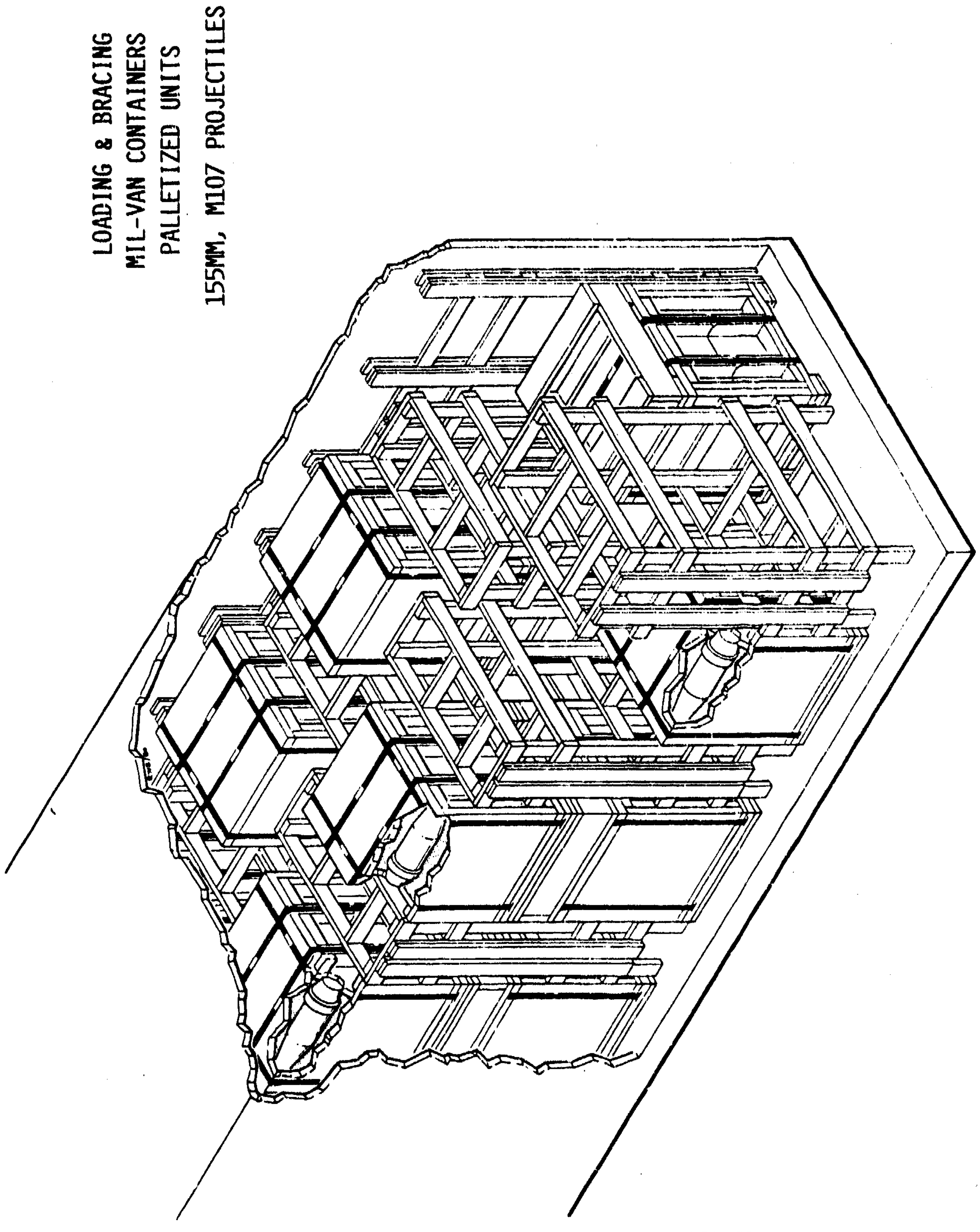
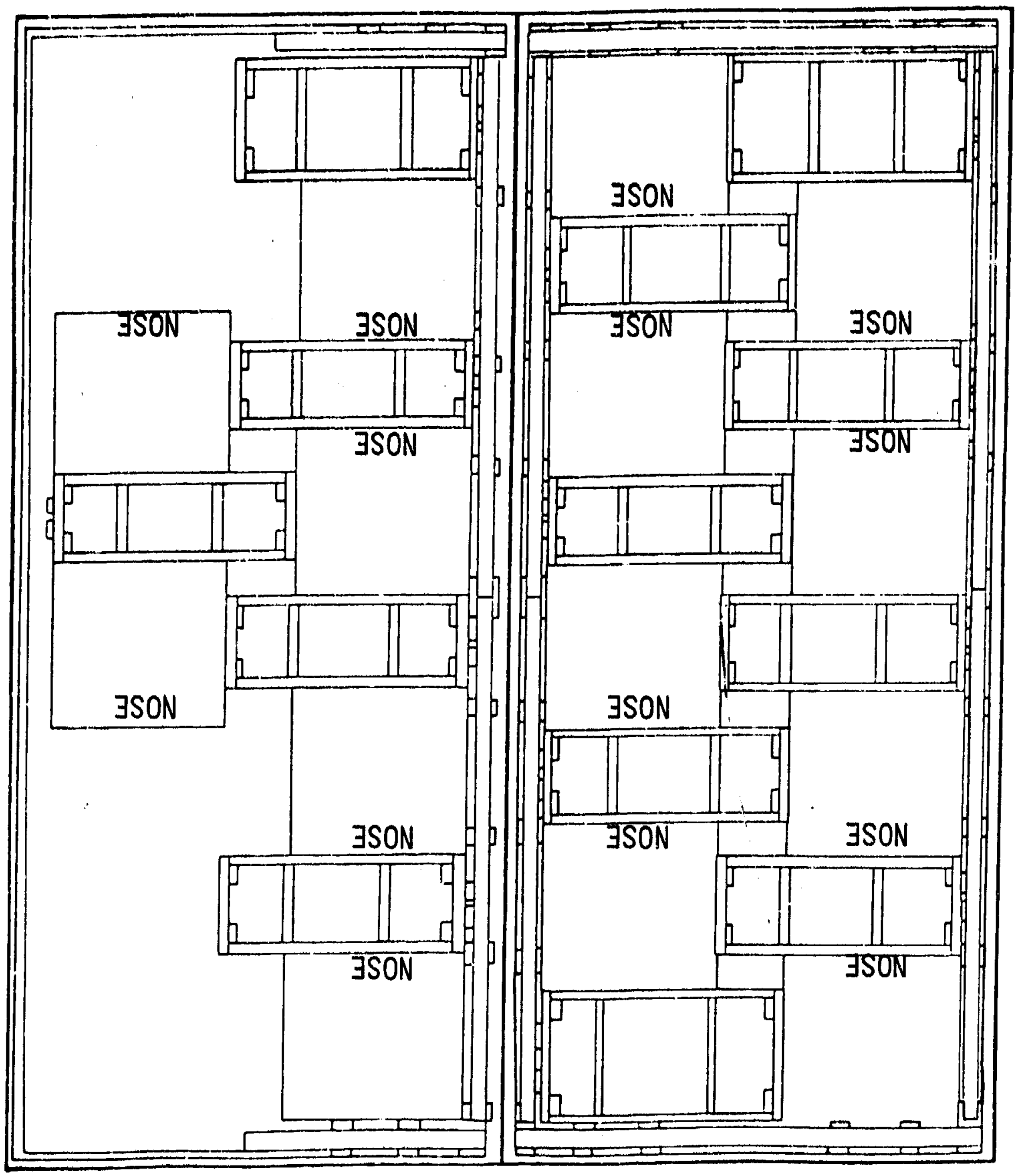


FIGURE 16. MILVAN PACKING ARRANGEMENT - METHOD II



LOADING & BRACING MIL-VAN CONTAINERS
PALLETIZED UNITS 155 MM, M107 PROJECTILES

FIGURE 17. MILVAN LOADING - METHOD II

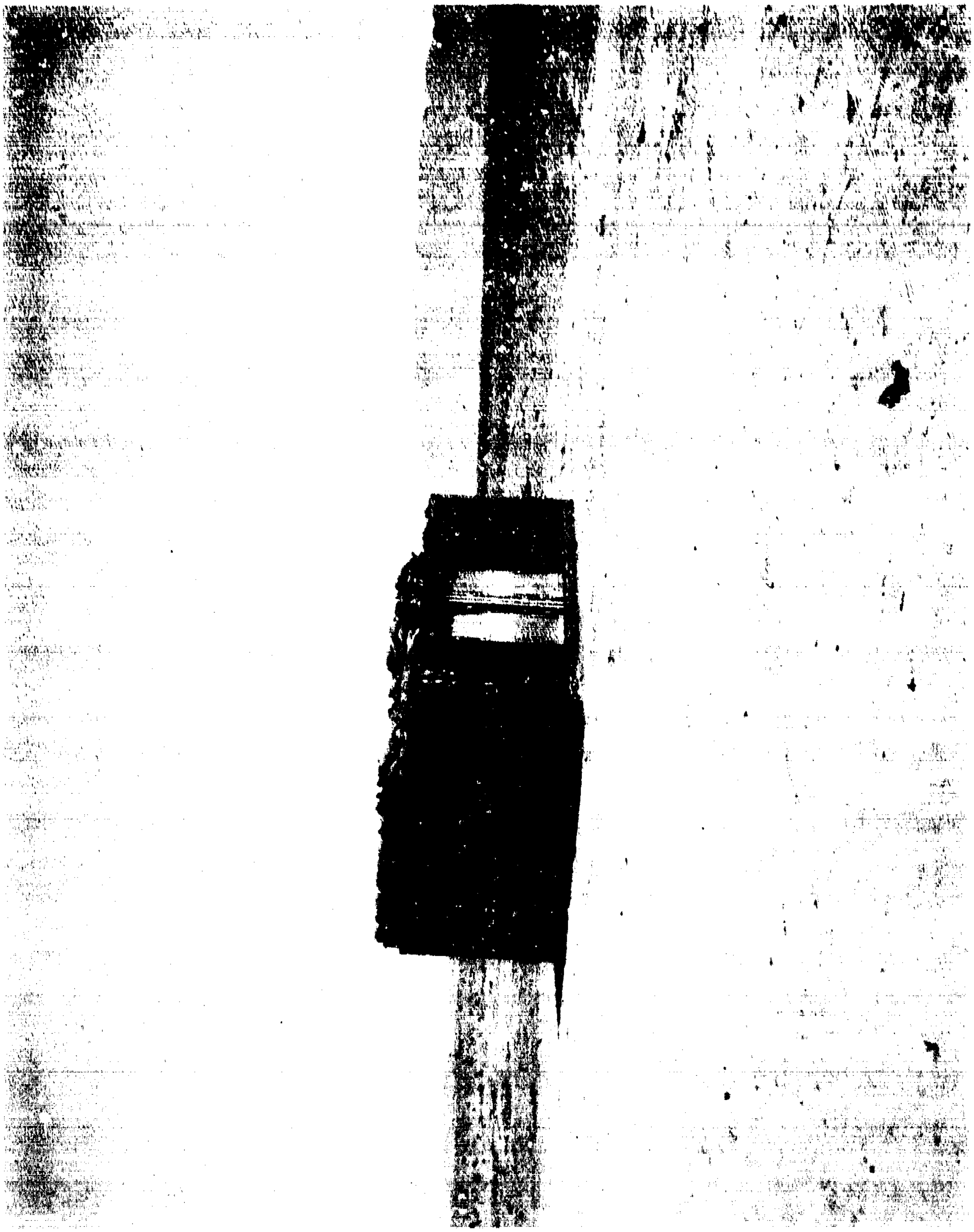


FIGURE 18. TEST SITE SETUP - METHOD II

FIGURE 19. POST FIRING TEST SITE - METHOD II

The Roseville Train Explosion Incident

by

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Abstract. On 28 April 1973, a bomb-laden train parked in a railroad yard in Roseville, California, underwent a series of explosions. Events leading to and during these explosions will be given in a technical manner.

INTRODUCTION

Early on the morning of 28 April 1973, the Roseville yard of Southern Pacific was shaken by a loud explosion. That was followed by massive explosions in a munition-laden train. This report discusses the events and facts that led to this train explosion. The actual cause of the accident may never be known with assurance. However, the preponderance of evidence indicates that the most probable cause was a fire in the floor of a DODX boxcar which was ignited by a misapplied and overheated high friction composition brake shoe as the boxcar descended the summit from Donner Pass prior to entering the Southern Pacific classification yards at Roseville, California. The plausibility of other events causing the explosions at the Roseville yard are considered and covered in this report. The various theories of causation were the bad bomb theory, the bad boxcar theory, the yard fire scenario, the tank car fire scenario, the fire in a red boxcar scenario, and sabotage. A brief background to the series of events prior to the explosions will be given, followed by a limited discussion on the various theories and scenarios.

EVENTS LEADING TO THE EXPLOSION

The bombs that were involved in these explosions were loaded at the Naval Ammunition Depot, Hawthorne, Nevada, during March and April of 1973. These bombs were the Mk 81 with a tritonal load. The bombs were loaded into 21 DODX 28000 series boxcars for movement via Southern Pacific Transportation Company's (SP) rail lines to the Naval Weapons Station at Concord, California. On 26 April 1973, the 21 DODX boxcars were taken to Thorne, Nevada, where they were picked up by a train headed for Sparks, Nevada. That train departed Thorne at 1630 hours and arrived in Sparks at 2215 hours the same date. At Sparks, the 21 DODX boxcars were picked up by a SP train which had come from Ogden, Utah. These events and those which follow are given in Figure 1. Just prior to departure, the SP train encountered coupling or air difficulties. The problem was apparently solved and the train departed Sparks at 2345 hours (27 April 1973). This SP train was known as the 2-WCM-YD-27, referred to hereafter as the "Roseville train" or "the E9117W". After the Roseville

train left Sparks, it began to ascend the eastern slope of the Sierra Nevada mountain range. The speed until it reached the summit was about 20-25 mph. After the train reached the summit and began its downhill grade descent, the train encountered coupling or air problems once again. This problem occurred between two of the DODX boxcars and the train came to an emergency stop at Cisco. The speed prior to this emergency stop was estimated at 38 mph. The train was delayed for about two hours because of two or more emergency stops (Figure 2).

Figure 2 is a plot of milepost versus time (hr:min) with corresponding events marked on the plotted line. For example, the summit is milepost 192 and the train was at this point at 0132 hours on 28 April 1973. One emergency stop was at milepost 180 with a corresponding delay until about 0350 hours. Before the Roseville train left the Cisco and Shed 10 area, a mail train passed it. At this time, the Roseville train had 110 railcars, a caboose, and three lead and four helper locomotives. Also, at least one helper locomotive was inoperative with regard to dynamic braking. As the train left the area of milepost 179, dynamic braking was used to control the train speed. At milepost 176, a light application of the brakes was made and released at milepost 174, but this did not increase the braking to a minimum of a 10-pound reduction of air. The engineer on the Roseville train failed to follow prescribed Southern Pacific procedures for releasing light applications of the air brakes which increased the possibility of a stuck brake valve on a DODX boxcar. The effect of such a stuck brake could have produced the brake malfunction phenomena reported by witnesses at milepost 158.2 and about milepost 156. A second light application of air brakes occurred at milepost 172 and increased brake application at milepost 158 in response to a yellow light. The yellow light was a warning to the Roseville train that it was getting too close to the mail train. The Roseville train came to a complete stop at milepost 155.7 according to the engineer, but the rest of the train crew did not remember this stop. A witness at milepost 158.2 had a tape recorder on which he was recording the sound of the trains. He reported seeing a red wheel and a burning brake shoe. The speed of the trains was determined from this tape recording; the speed of the Roseville train was calculated at 35 mph. This speed exceeded the limit by at least 5 mph, or 10 mph by an earlier accepted speed limit.

The next set of three witnesses saw the Roseville train at milepost 156. They reported seeing smoke coming from this train and a red light as the train went by them. The train was over a mile long and came to a complete stop at milepost 155.7 (according to the engineer) which is 0.3 of a mile further down the track. Therefore these witnesses should not have seen the red light before the train had stopped and started up again. The next sign of heavy black smoke was at milepost 125. The estimated time was 0545 and the witness described the train speed as very slow. The average train speed through this area was 45 mph as calculated from the hot box detector at Colfax and at Rocklin. One witness at milepost 113 saw some light smoke coming from this train, but identified the railcar as one different from the silver painted DODX boxcars. No more smoke was noted until after the Roseville train was parked in the Antelope portion of the Roseville yard.

The Roseville train arrived at the Roseville yard at 0605 (East end) and waited 20 minutes before being allowed to enter the yard. It moved slowly through the yards to the westward or Antelope yard and the train pulled through track A-7 at 0643. The train was too long for track A-7 and so it was broken between the third and fourth DODX boxcars. The three DODX boxcars and the other 16 railcars were shoved into track A-3. The Roseville train was parked at 0705 hours. The approximate location of the various cars on tracks A-7, A-6, A-5, A-4, and A-3 is shown in Figure 3. The westward end of the DODX boxcar on track A-7 was too far west and for this reason was fouling the lead track. This fact was brought to light by the Southern Pacific's attorney during the deposition of their witnesses. They stated that the lead was not fouled prior to the first major explosion in the Antelope yard and that this explosion pushed the DODX boxcars ahead by some 50 feet. Had this been true, there would have had to have been one less DODX boxcar on track A-7 since each DODX boxcar is a little bit over 50 feet. Once this was established, Southern Pacific did not pursue this idea any further.

Figure 4 is a general layout of the west end of the Antelope yard and the location of some of the witnesses. Information on what occurred in the yard before the first major explosion was taken from early statements, depositions, and personal interviews. The first reported smoke seen in the yard was by an SP worker at position Y-15 at 0720. At about 0730-0740, a local resident at position Y-16 saw smoke and a boxcar burning. He watched the boxcar burn until an explosion occurred. The witnesses at Y-13 were both inside and outside their houses when they became aware of a fire in the Antelope yard. One witness heard from her bedroom two men standing next to a locomotive say there is a fire in the yard. She and her son saw this locomotive and train leave the area. At this time they also saw scooters going toward the shandy at the west end of the yard. After this they went outside and watched the burning boxcar for about 10 minutes. The apparent time the train left the yard was 0745. According to one witness, the boxcar burning was not the car that exploded. They seem to recall two explosions. The next set of witnesses were at R-12. They heard what they thought to be a very loud humping sound coming from the yard. One witness noted the time to be 0750. These witnesses went outside their house and observed a "burning tank car" on top of an overturned boxcar. They watched this burning tank car for several minutes and then a big explosion took place. They were blown back into their house which resulted in some injuries to the family. The wife took the children to the hospital while the father went to the Trakadero Bar. While at the Bar he met an engineer who said he was on the "bomb train". His switchman was with him. The witness heard the engineer say to his switchman something to the effect, "They parked my train with a DODX car hot box next to a leaker." Since this witness saw a burning tank car on the side of an overturned boxcar, he felt this may have been the "leaker" in this part of their conversation. The SP engineer confirmed that he was at the Bar, but did not remember the "leaker" as part of the conversation.

A fire call reportedly heard at 0730 by an SP worker, as described during an interview taken at the change of work shift, was later denied during his deposition. Another witness at about 0745 saw the crossing closed at the west end of the

Antelope yard; and while heading north on the North Antelope road, he also saw the roof raised on a boxcar by a minor explosion (Y-4). The next witnesses were at Y-1. They saw the burning boxcar, and one said it was a red-colored car. As they proceeded up the North Antelope road, a big explosion took place. Another witness was in a VW bug located at the spot where the North Antelope road is closest to the railroad yard when this explosion took place. This witness could not be found for an interview. The car was left at the spot and was later completely destroyed by the train explosions. The next witnesses were behind this VW car when the explosion occurred (Y-2). One of these witnesses saw the burning boxcar and watched this boxcar burn. He also described it as being red. He watched the boxcar explode right in front of him while he was sitting in his pickup-camper. The camper suffered major damages. Y-1 and Y-2 heard the time on the radio as 0751 as they were approaching the Antelope yard. The firemen at R-2 and R-3 heard an explosion and R-3 reported the fire at 0759. Also, at about 0750, witnesses at Y-13 saw a boxcar on fire and observed the boxcar explosions. An SP carman (Y-3), at the time of the first humping-like noise, said he was at the east end of the cars on track A-3 and was ready to perform an air check on the cars on the runaround track. He saw a boxcar burning with its roof raised up. He was told to leave the area because of the danger from the munitions in these boxcars. As he was leaving, the boxcar exploded, knocking him down to the ground. He observed fire all around him, boxcars blown over, and boxes falling out. As he tried to leave again, he made it to a switch box before the next explosion hit. This was the major explosion at 0803.39. Other SP witnesses reportedly heard two explosions close together while other witnesses said they did not hear two explosions. One witness standing outside her house took a picture of the yard at 0800 ±15 seconds showing heavy smoke in the yard prior to the major explosion.

In summary, some witnesses saw a burning tank car; others a burning red boxcar; also some early smoke in the yard; and possibly a hot journal box. The fire (initial) seemed to be situated at different places depending on the location of the various witnesses.

THE EVENTS AFTER THE MAJOR EXPLOSION

The first major explosion was placed at 0803.39 because that explosion was recorded at the Seismographic Station (Oroville and Jamestown), with a reading of 1.5. The next major explosions were at 0839.07 (1.5), 0843.54 (1.6), 0944.07 (2.0), and 1006.54 (1.6). Other big or even major explosions did occur, but were not recorded at the Seismographic Stations. Many events took place during this time, but not all of them can be cited in this report. Information obtained from early photos of the area, taken during the 10-20 minutes after the first major explosion, would indicate that several DODX boxcars and other railcars were involved in a yard-type fire and/or explosions. This will be shown under the different theories of causation.

THE THEORIES OF CAUSATION

The first major explosion occurring at 0803.39 in the Antelope railroad yard was almost certainly caused by a DODX boxcar on track A-7. What caused that boxcar or boxcars to explode is the question! A number of theories and scenarios were advanced by both Southern Pacific and the United States attorneys. These included the bad bomb theory, the bad boxcar theory, the yard fire scenario, the tank car fire scenario, the fire in a red boxcar scenario, and sabotage. None of these theories or scenarios have positively established the cause of the initial explosions or the first major explosion. Of these, the bad bomb theory was the first considered by both parties; and the others as the case developed.

The bad bomb theory was of major importance to both parties; Southern Pacific because of the damages that occurred in the yard and to the United States and other groups because having a "bad bomb" in stock which might explode spontaneously would be unacceptable. The explosive used in these bombs was studied extensively and found to be of good quality. From information available, the issue of a "bad bomb" causing the explosion in the Antelope yard was completely removed by the Judge in this case.

The bad boxcar (DODX) theory became the main issue in this case. The basic points were: narrow spark shields, wrong brake shoes, and inadequate maintenance and upgrading of the 28000 series boxcars. Obtaining information on these points required a detailed study and understanding of the operation and braking of a DODX boxcar. The operation and maintenance of the DODX boxcars was a key issue in the case and caused much concern on the part of the Army and the Navy.

Studies at the time centered on how ignition of a DODX boxcar could take place. Experimental data from SP, WABCO, and NWC were used to determine various fire-causing conditions associated with stuck brake shoes, oil and grease underneath a boxcar, excess oil in journal boxes, narrow spark shields, and wooden boxcar floors. Also studied was how fire would spread along the floor and walls once it got inside the boxcar and how bombs would react to this fire in regard to the level of heat, type of pallets, cook-off times, and type of reaction. In summary, a cast iron brake shoe in a stuck condition could start flaming in about 3-10 minutes depending on the brake horsepower being applied. Once this type of brake shoe was flaming under these experimental conditions, the heat output would be in the order of 5-10 Btu/ft^2-sec and would cause sustained ignition of a wooden floor under a boxcar in about 1-2 minutes. If flaming sparks were to continue to impact the floor, burn-through could occur in about 10-20 minutes after sustained ignition. Once the fire is inside the boxcar, conditions within that boxcar will determine the time to cook-off of the bombs present.

Another source of fire is from high friction composition brake shoes. The heat level from this type of brake shoe is much lower than that from a cast iron brake shoe; in the order of 1.5-2.5 Btu/ft^2-sec for a stuck condition. Within the life of the brake shoe, this heat level is too low to cause direct sustained ignition of a wooden

floor; but flames from this shoe can easily ignite any oil and grease located underneath the boxcar. This type of fire is difficult to sustain and conditions under a boxcar must almost remain static in order for the fire to get a good start on the bottom of the wooden floor. Under these conditions, the estimated time to burn-through is about 1 hour ±1/2 hour after ignition of the floor. Again, the fire gets inside the boxcar.

A further source of fire is from the friction-type journal box. It is possible for a flaming brake shoe, either cast iron or composition, to ignite the oil in a journal box via the oil coming out the back or through the front cover cap (if open). Once this oil is ignited, it can burn for many hours at a very low flame. Under these conditions, very little heat is transferred to the bottom of the journal box until all of the oil is burned away. The box then starts to heat up very quickly because of lack of oil to the bearings. Therefore, until the oil is almost burned away, a hot box detector may not detect a journal box with just the oil on fire. When oil is burning in a journal box under static conditions, the burning oil will flow out of the journal box onto the ground and ignite any oil or other fuel located there. The fire from a journal box (if open) is in a direct line above where the floor meets the wall of a boxcar. The air gap between the floor and wall form a chimney effect and draw the fire up inside the boxcar and in between the walls. The fire in this case can be inside the boxcar within as little as 3-4 minutes and to the top of the inside wall in less than 20 minutes.

These conditions were studied in regard to a DODX boxcar to show how a fire could get inside a boxcar from a stuck brake shoe or a burning journal box.

Once burn-through of the floor had occurred, the time to cook-off of the bombs was determined experimentally. The time to cook-off was somewhat dependent on where the fire burned through the floor. If the burn-through occurred in the floor away from the walls, the time to cook-off of Mk 81 bombs in a steel pallet would occur in about 1 hour. If the fire came up the sidewalls, the time to cook-off could be as short as 20 minutes. Under normal conditions of the tests with a low fire out of a journal box, flames would not reach the floor or wall of a boxcar. In order for a fire to reach the floor-wall area of a boxcar, the fire would have to come from the track. The experimental data presented for a DODX boxcar could account for many of the observed sightings of smoke coming from the Roseville train as it came down from the summit to the Roseville yards. Figure 2 shows some of the calculations used in this study on a boxcar fire.

The yard fire scenario is based on available statements, interviews, depositions, and on-site inspection of the Antelope yard. For a yard fire to start, certain conditions must be favorable; namely, fuel and some sort of an ignition source must be available. One fuel source would be the oil between the rails in the yard. An on-site inspection of the Antelope yard shortly after the accident and in an area that was not yet rebuilt, showed oil a couple of inches deep in various places. Another source of fuel is wood chips found in the yard. When open wood chip hopper carr are humped, stopped, or moved, chips are shaken out of the hopper cars onto the ground and in between the rails of a track. The combination of oil and chips is easier to ignite than

would be either oil or chips alone. When burning, the chips would give off white smoke while oil would give off black smoke. Black smoke can visually appear almost white depending on the location of an observer with respect to the smoke and the sun. On track A-9, several open hopper cars with wood chips were located across from the DODX boxcars on track A-7. Track A-8 was open (see Figure 3).

Possible ignition sources would be the yardbirds (scooters), journal box fires, stuck brake shoes, and railroad flares. From 1967-1974 the Roseville yard received an average of 97 fire call reports per year during the 8-year span. If the Roseville train did indeed come into the Antelope yard with a hot journal box, both a fuel and an ignition source were readily available for causing a yard fire. The time period during which the DODX boxcars were first parked on track A-7 at 0643, and 0755 when the first apparent explosion occurred, is over an hour. This is about the time frame found experimentally at NWC for an explosion to occur with this type munition. The Antelope yard explosion occurred in about 72 minutes; whereas the one live DODX simulated yard fire test, using an oil-soaked track under the boxcar, took 77 minutes. It was further noted that the smoke level can be very low when visually observed if the wood chip level is higher than the level of oil present in the yard. The smoke almost disappears after a few minutes unless the fire gets down to the level of the oil. The height of the flames is about 1-3 feet which is almost invisible during daylight hours.

The tank car fire scenario is based on the same information as that used for the yard fire scenario, but with the additional information of the sighting by several witnesses of a tank car on top of an overturned burning boxcar prior to a major explosion occurring in the yard (0750). One witness at position R-4 shown in Figure 4 stated that he saw "gray smoke". He reported seeing one tank car on its side and a portion of a boxcar by the main line at a time which was just minutes after the major explosion. Another witness at position Y-13 shown in Figure 4 remembered, during his deposition, that he saw a gray tank car before the major explosion took place (estimated time was 0745). No physical evidence of a tank car was found in the yard. However, photos taken by the National Guard show a railcar frame that strongly resembles a frame used in tank cars. The frame in the photo has only the center strong stringer with no side arm braces or rails. A second photo shows a crane removing this frame from the area near where the witnesses at R-4 described seeing an overturned tank car. From the description of the fire by the witnesses, the fuel in the tank car was a flammable liquid, but not likely propane or butane. The time to cook-off of bombs in a boxcar would be about the same for the yard fire calculation except that with the addition of a tank car to spread more fuel around, more boxcars would be involved in this type of a yard fire at one time. This may account for two large explosions within such a short time frame. If according to witness Y-3 the first explosion had cargo falling down onto the ground and other boxcars being blown over, it is not very likely that this boxcar with its scattered cargo could explode again a minute or two later with the magnitude recorded at 0803.39.

Sabotage is always the first thought in an explosion of this type. EOD teams were used to clean up the Antelope yard and the surrounding areas. A member of that

EOD team found a small golf ball-sized piece of what he thought to be C-4 plastic explosive. The material was analyzed by the FBI laboratory and was found to indeed be C-4 explosive. Also found in the debris in the Antelope yard were some mortar fins. Each of these fins had a lot number engraved upon its shank. From these numbers it was determined that these fins were manufactured during 1971 at a manufacturing facility in Portland, Oregon. They were shipped to either the Volunteer Army Ammunition Plant in Milan, Tennessee, or to the Longhorn Army Ammunition Plant in Texas. At Milan the mortars were loaded with high explosives, and at Longhorn they were loaded with incendiary or illumination loads. Some of the mortar fins from the same lot as those in the Antelope yard were, after being assembled on HE mortars, sent to NAD, Hawthorne for storage prior to 28 April 1973. No tool marks of any kind were found upon these fins, leaving them a mystery. The reason for the presence of these items found at the scene of an unexplained explosion and their relationship to it was not explained, but any theories were discarded in favor of a causative boxcar fire at that time.

The fire in a red boxcar scenario is based on eye-witness reports of seeing a red boxcar on fire prior to an explosion at areas Y-1 and Y-2. Their view to the side of this boxcar could not have been blocked, otherwise they could not have seen the color. In an early statement by an SP car foreman (Y-18), he reported he had heard over the radio that there was a fire in the yard. He drove his pickup truck to a point where he was south of the boxcar on fire. He stopped and went over to see where the fire was located in the yard. He observed a boxcar on fire with flames about a foot high above the top of the boxcar. Also he said that the boxcar looked like it was just another Southern Pacific car, same color as the normal Southern Pacific cars. It was assumed that normal SP cars are a dull red color. Another observer at position R-2, who was a Lieutenant in the Citrus Heights Fire Department, stated that at about 75 meters from his trailer was a boxcar on fire with flames 4-5 feet above the top of the boxcar. He believed the car was reddish-brown in color, but was not positive. Even under the traumatic conditions of this accident, several witnesses later reported seeing a red boxcar on fire prior to the big explosion or the major explosion at 0803.39.

THE COURT CASE AND SETTLEMENT

The court case that evolved out of the causes of the Roseville explosions of 28 April 1973 went through a preliminary injunction (April-May 1974) and into an acutal trial on 7 November 1977. The United States' defense of the litigation was to some extent hindered by changes in Department of Justice personnel assigned to the case. This lack of continuity, along with other issues, caused the Southern Pacific and the other plaintiffs and defendants to focus on the United States as a target defendant. At stake, initially, were claimed damages amounting to about $150,000,000. The court case centered primarily on the condition of the DODX boxcars and covered such issues as the narrow spark shields, brake shoes used, maintenance, reares, air brake tests, etc.. The bomb issue was defeated by the U.S. in court. At further issue was the location of the first DODX boxcar to explode, and the hidden fire inside a boxcar.

During the actual trial between SP and the U.S., the United States mounted an extremely strong defense which prompted fair settlement offers from the other parties. From the attorney's report of the court case, 124 plaintiffs' cases involving 805 claimants were settled for a total of $18.8 million on 28 April 1978. Of that amount, Southern Pacific paid $9,780,000, the United States paid $5,475,000, and 12 other railcar and component manufacturing defendants paid $3,479,000. The trial continued until the summer of 1979 when settlement negotiations, over which the trial judge presided, resulted in a settlement of Southern Pacific's $40 million claim. Under that settlement agreement, the United States paid SP $3.75 million and gave up its counterclaim for $1.3 million for the loss of its bombs. Of the $32,446,000 lost as a result of the Roseville explosions, SP paid $18,442,000, the United States $10,525,000, and the 12 other defendants $3,479,000.

LESSONS LEARNED

The report by the attorney on this case listed several lessons learned regarding operational safety and litigation defense strategy. These are taken from his report and given verbatim. "Satisfying federal safety regulations *does not* equate non-negligence. To avoid or minimize tort liability, particularly when dealing with hazardous materials, MTMTS and all DOD shippers must adopt a policy of staying at the forefront of the industry's actual safety standards. Unless changed, the current DOD policy of imposing no higher safety standards for DOD shipments than the minimum industry and regulatory standards will continue to subject the United States to tort liability. A forward looking program which seeks to identify emerging operational hazards and eliminate them prior to a catastrophe is required. Increased Command attention to safety in operations is necessary to insure that program managers make sound decisions regarding safety improvements.

"In litigation involving catastrophic accidents, a special litigation team with good prospects for continuity is required to mount an aggressive and effective defense effort. Reliance on standard litigation procedures will not be sufficient to encourage fair and early settlement or achieve a *prompt* and just adjudication. Unless such litigation can be resolved quickly, litigation costs will be unacceptably high."

CONCLUSION

Although the Roseville train explosion in the Antelope yard occurred on 28 April 1973, litigation did not end until 28 January 1980 when an out of court settlement was reached. The purpose of this report was to list and describe possible causes for the explosions in that yard, rather than to present the legal portion of the case. The legal portion of the case has been documented by the U.S. Attorney in his report entitled "The Roseville Train Explosion. Final Litigation Report."

The actual cause of the explosions in the Antelope yard is not known with complete certainty. A number of theories and scenarios overlapped each other.

Although there was no factual testimony or physical evidence to support a yard fire scenario, the records of yard fires occurring in the fuel and wood chips found in the Roseville yards, along with the various ignition sources available, did support this scenario as a possibility. Further data from experimental tests at NWC and WABCO (with SP) indicate that a boxcar on fire would have had the bombs reacting before reaching the Roseville yards. Other munition boxcar fires usually have munition reaction times of 1.5-2 hours after conditions such as a stuck brake have occurred, whereas the Roseville train took almost 4 hours to react. With these data, the possibility of a yard fire cannot be entirely dismissed.

The yard fire, the tank car, and the red boxcar scenarios are based primarily on witness observations of the situation in the Antelope yard that morning. Only a brief witness list is given in this report. Some witnesses saw a tank car, others saw a tank burning, and one saw a blown tank car. These witnesses were at four different locations. Also what one witness or group of witnesses may observe at a given location may not be visible to another witness or group at another location. For example, one witness or group would see a red boxcar burning, another, a tank burning; another, the car burning was not the one that exploded; still another, a silver gray car was burning; and to yet another, boxcars blown over and fire spread all around. A note at this point: Explosives are used to blow out fires and usually do not spread a fire; circumstances thereby suggesting a liquid-type fuel explosion. Testimony from the witnesses would indicate that two or more cars were on fire prior to the major explosion at 0803.39. Expert measurements made from a photo taken at 0815 from the North Antelope road showed that a fire, with heavy smoke and flames, was about five boxcars wide. From Figure 3 this would include DODX boxcars 11 through 15. The time between one DODX boxcar reacting and the next DODX boxcar reacting was about 15-20 minutes, except between boxcars 1 and 2 where the time element was 48 minutes. The fire spread from boxcar to boxcar via the track. This was determined from photos taken between 0900 and 1107. Also, another photo taken at 0815 shows DODX boxcar 11 laying over on its side.

From observations, statements, and depositions of witnesses, early photos from ground level and aerial coverage, and also from experimental studies at NWC, the yard fire, fire in a red boxcar and tank car fire scenarios seem to fit the data better than the bad boxcar theory. In the studies at NWC and brake shoe studies at WABCO, the boxcar would have been in trouble before it reached the Roseville yards. When many of these questions may have been answered, the Roseville Case was settled out of court.

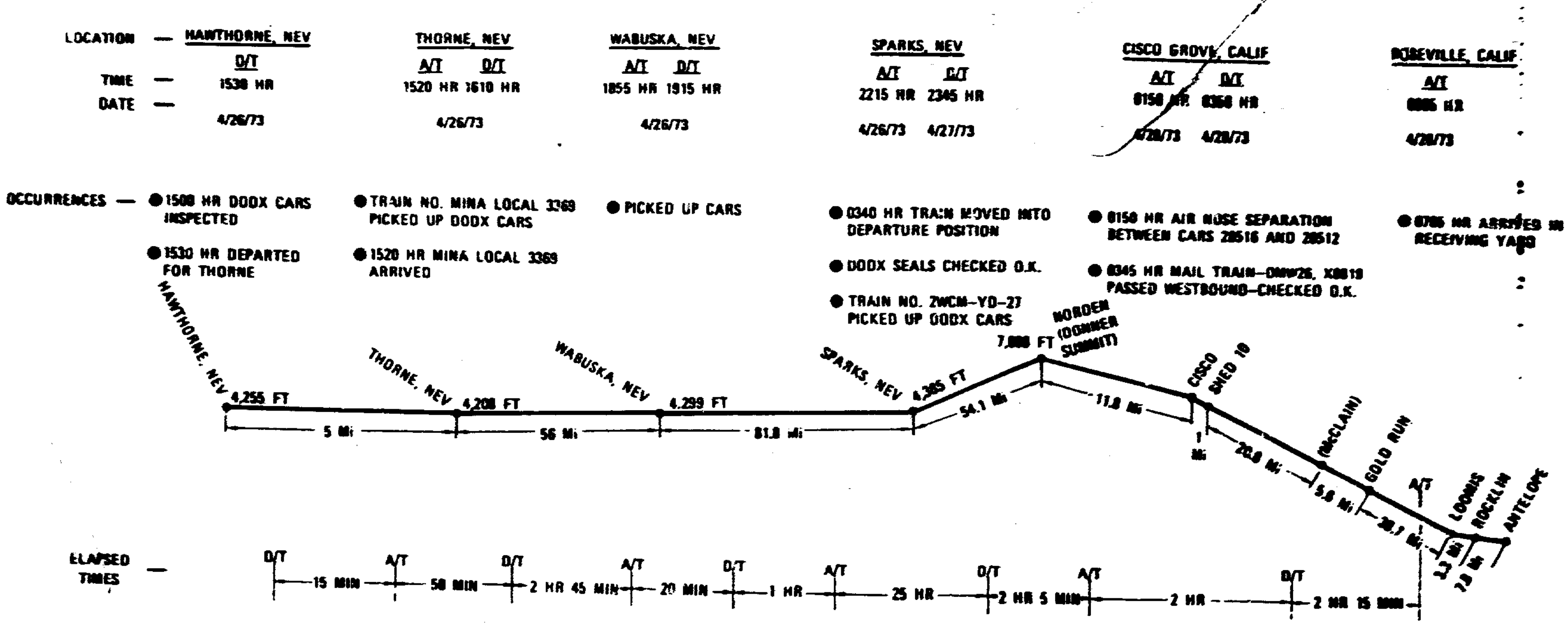

FIGURE 1. Plot of Events vs. Time and Distance.

LOCATION	M.P.	TIME	EVENT	EVENT TIME (MIN.)	DATA SOURCE
NO. 1	176	04:05	BRAKE APPLICATION	---	EGGERS
NO. 2	170	04:15	CAST IRON SHOE FLAMES	10	S.P./D-1,-2,-4,-5
NO. 3	167	04:20	WOOD FLOOR IGNITION	15	S.P./D-2,-4
NO. 4	162	04:29	FLOOR BURN THROUGH	24	S.P./D-2,-4
NO. 5	128	04:38	FLOOR BURN THROUGH/BOXCAR C.O.	93	(SP/D-2,-4)+(NWC, BOXCAR C.O.)
NO. 6	125	05:42	FLOOR BURN THROUGH/BOMB C.O.	97	(SP/D-2,-4)+(NWC, AVE BOMB C.O.)
NO. 7	106	06:11	FLOOR BURN THROUGH/MAX BOMB C.O.	126	(SP/D-2,-4)+(NWC, SCO-99)

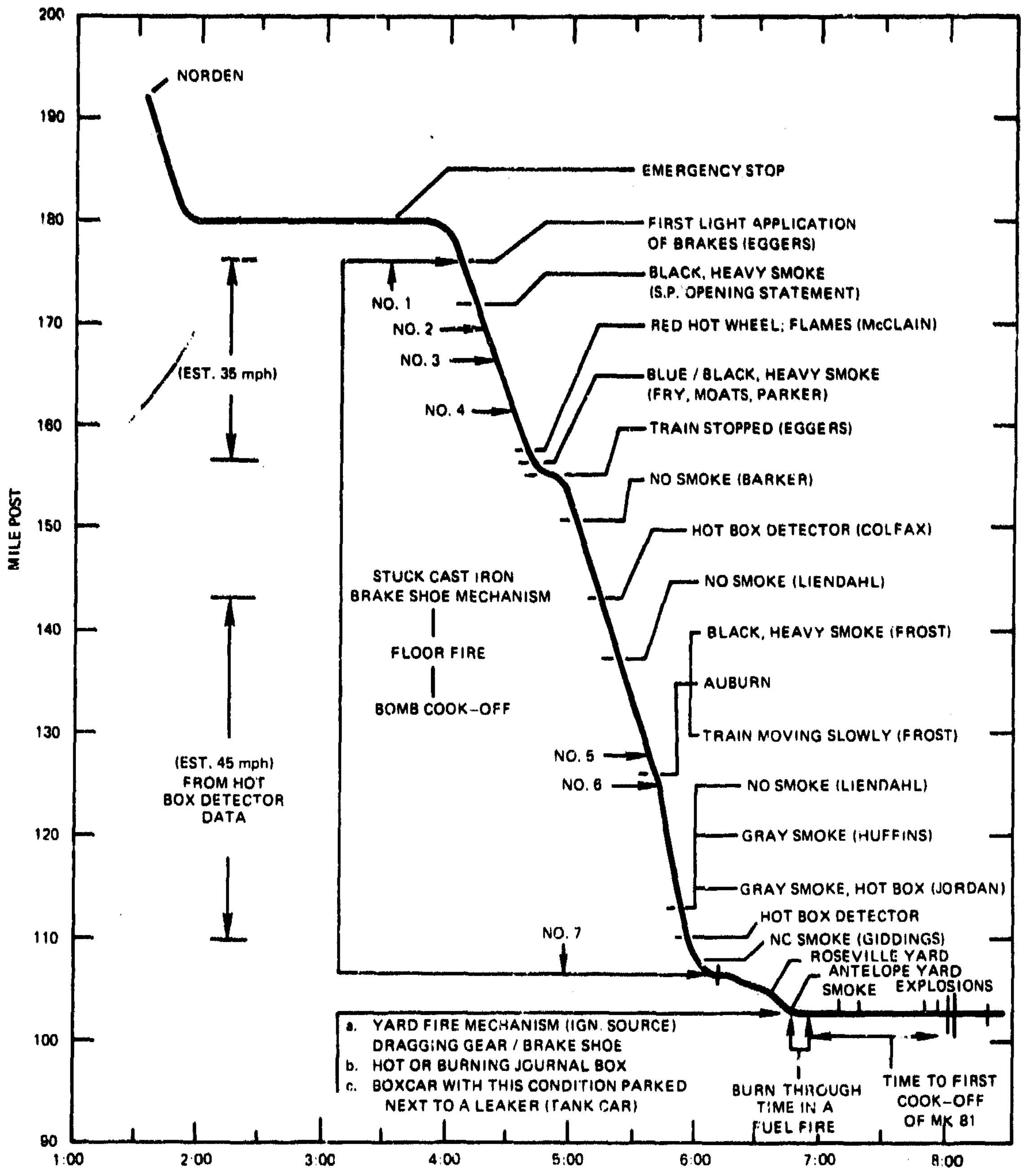

FIGURE 2. Plot of Milepost vs. Time.

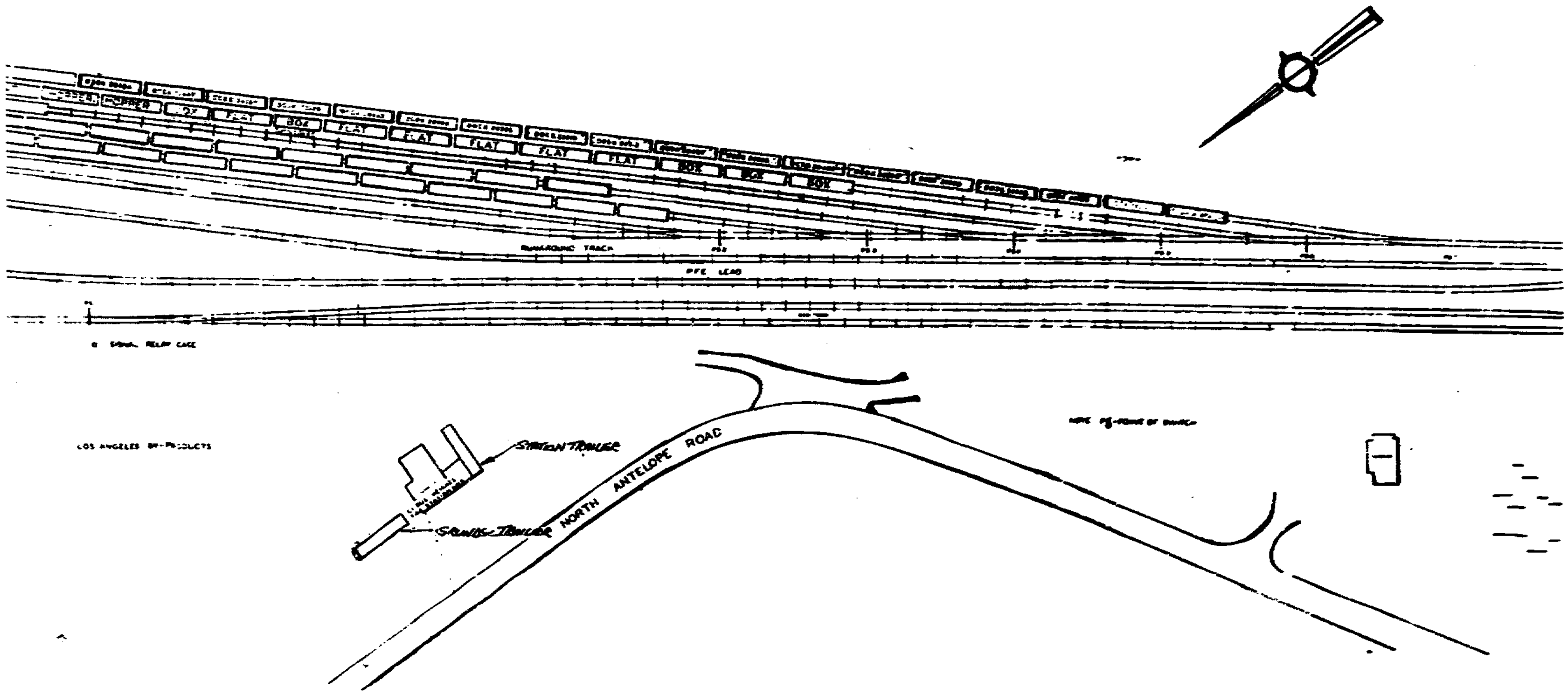

FIGURE 3. Track Layout in the Antelope Yard.

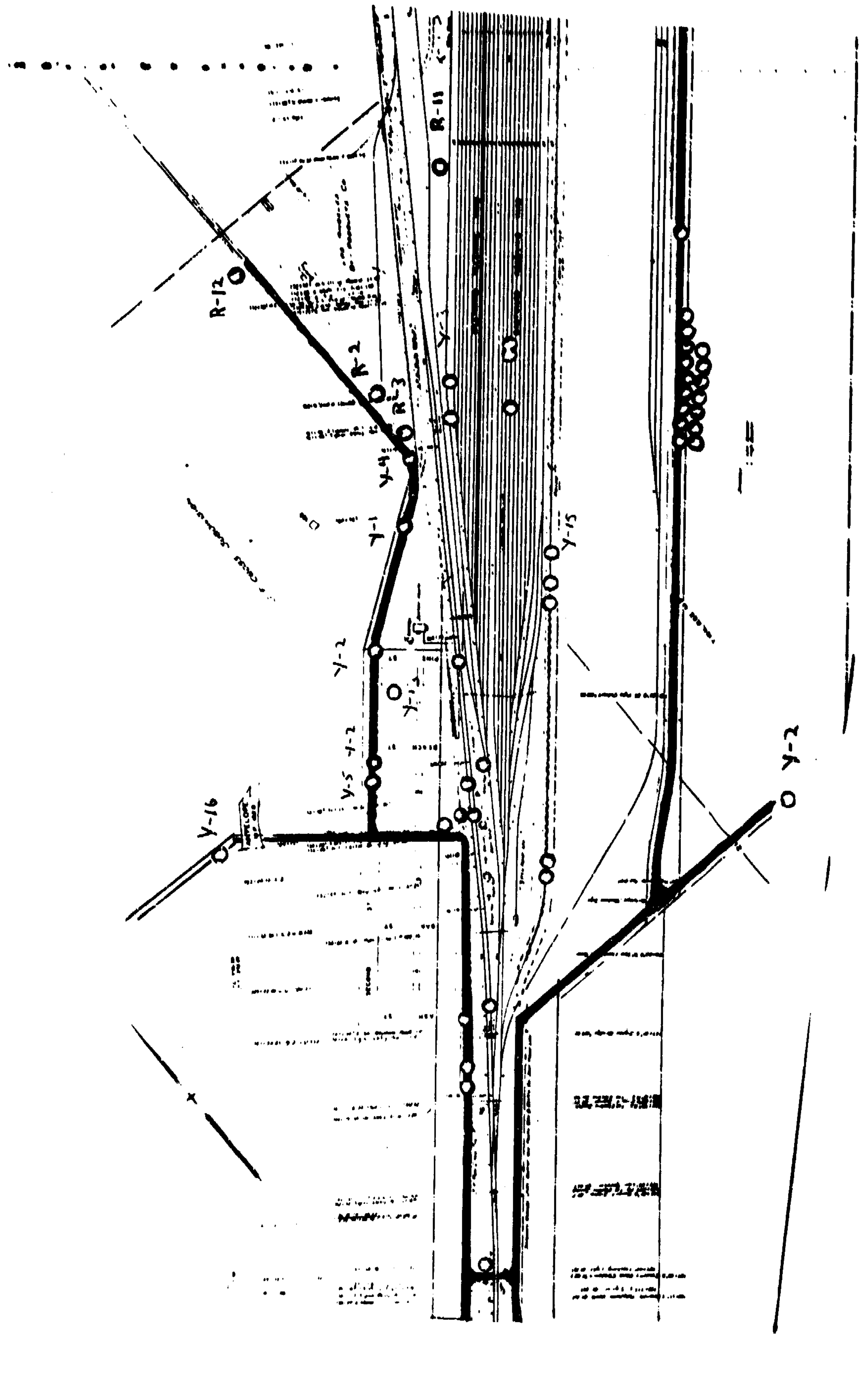

FIGURE 4. Witness Location in Antelope Yard.

THE CAUSES OF NITROGLYCERINE EXPLOSIONS

A Statistical Survey

by

G. S. Biasutti

Dr Ing. Mario Biazzi SA
Vevey, Switzerland

Since the beginning of the commercial manufacture of nitroglycerine the toll taken in human lives and the destruction caused by accidental explosions has been appalling.

I have collected a certain number of case histories concerning accidents in the explosives industries with particular regard to their causes.

On the basis of this information, I wondered whether, as a result of the large number of accidents cited, some statistical evidence of recurrence under particular conditions and during particular periods of time could be drawn.

As a first step I decided to investigate the accidents involving the manufacture, storage and handling of nitroglycerine.

Out of 630 case histories, 158 concern nitroglycerine.

Disregarding the accidents of which the cause was never found, 101 case histories remained where their cause had been determined either with certainty or with a reasonable degree of probability.

The causes of nitroglycerine explosions fall into the following categories:

1. Mechanical (shock, friction, vibration).
2. Chemical (self-decomposition, run-away reaction).
3. Thermal (heat, electric energy).
4. Indirect (fire, lightning, explosion).

I was interested to find out how these causes of accidents were distributed in the period of my survey covering 110 years.

I have divided this period into three parts:

I	1870-1930	Nitroglycerine is manufactured by the conventional batch process.
II	1930-1960	Advent of continuous nitration.
III	1960-1980	Introduction of automation, remote control and emulsion transport

The following table shows the distribution of the accidents in these three periods.

	1870-1930		1930-1960		1960-1980	
	Cases	Percent	Cases	Percent	Cases	Percent
Mechanical	19	49	8	32	14	38
Chemical	17	43.5	13	52	10	27
Thermal	-	-	-	-	9	24
Indirect	3	7.5	4	16	4	11
Total	39		25		37	

The accidents due to mechanical causes consist mainly of dropping of cans, hitting of metal parts, spillage of nitroglycerine, turning of ceramic valves, vibration of cooling pipes. There are two cases (in the third period) where detonation was initiated in a water recyclation pump where nitroglycerine had penetrated.

The accidents due to chemical causes are usually due to unstable spent acid (wrong nitration ratio), localized heating from lack of cooling or stirring, presence of impurities, poorly washed nitroglycerine.

The accidents due to thermal causes are mostly due to adiabatic compression of air bubbles; they appear only in the last period, when the method of transferring nitroglycerine as a water emulsion was introduced, and before the theory of Bowden and Yoffe was understood. This theory suggests that adiabatic compression of gas bubbles in a liquid explosive may produce enough heat to initiate a detonation.

The accidents due to indirect causes are not considered for this survey.

Looking at the above table we can note the following facts:

1. The sharp fall after the first period of the accidents due to mechanical causes.

2. The decrease of cases of self-decomposition after the second period.

3. The appearance of new type of accidents due to the adiabatic compression of air bubbles.

This result corresponds to our expectation.

The advent of continuous nitration had a favourable influence on the occurrence of accidents due to mechanical causes, as much less manual handling was necessary.

There was no decrease of frequency of accidents due to self-decomposition by the introduction of the continuous process. In fact this process does not eliminate the causes of errors concerning the control of the chemical reaction.

Only the introduction of automation and remote control in the third period which allowed to partly eliminate the human factor, helped to reduce the frequency of the accidents.

* * *

I also wondered whether I could find any statistical evidence of the better safety of the continuous versus the batch manufacturing process.

For this survey, only the accidents strictly connected with the manufacture of nitroglycerine have been considered, disregarding those which occurred during storage and handling. Accidents of which their cause has not been determined are shown.

	Batch	Number of fatalities	Continuous	Number of fatalities
Mechanical	36	35	1	-
Chemical	31	33	12	3
External	8	7	2	-
Unknown	35	131	7	7
Total	110	206	22	10

The mechanical causes of accidents outnumber the chemical causes in the batch process, while they were only one against twelve in the continuous process.

The most remarkable result of this survey is the much smaller incidence of fatalities by the continuous than by the batch process.

As a conclusion, it can be affirmed that the continuous process and the application of remote control have introduced an unprecedented degree of safety in the manufacture of nitroglycerine.

At the present time the most frequent causes of accidents in the manufacture of nitroglycerine are self-decomposition and adiabatic compression.

The first cause can be eliminated by paying more attention to the chemical control of the reaction and to the purity of the raw materials.

To eliminate the second cause, care must be taken to avoid blunt energetic changes in the hydraulic system for the emulsion transport of nitroglycerine.

Analysis of an Otto Fuel II
Pumping Incident

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Naval Ordnance Station
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INTRODUCTION

Otto Fuel II is a liquid monopropellant having a nitrate ester base. Developed at the Naval Ordnance Station, Indian head, Maryland during the early 1960's, it is in extensive use as a torpedo propellant by the U. S. and its allies. Transfer is by pumping in many situations. This incident review is intended to provide some experience by which pumping and piping installations can be evaluated for a potential hazard.

BACKGROUND

The monopropellant is produced by a Biazzi nitroglycerin continuous process. The nitration and supporting buildings arrangement is shown on Figure 1, Nitration Facility Map. Nitration in Building 786 produces either NG or Otto Fuel nitrate ester. Products flow thru separate lines to the different hold or store houses. Building 1463, contains the nitrate ester hold tanks and Otto Fuel formulation tank. Nitrate ester from the hold tanks is gravity transferred to the formulation tank which contains a premix of the other constituents of Otto Fuel II. The mixture is agitated for blending, and dried by air sparge in the formulation tank. Concurrently, the fuel is filtered to remove solid sodium carbonate residues from processing materials. The completed monopropellant is either held in the tank or transferred to tank truck or drum loading facilities. The transfer line is a recycle loop as shown in Figure 2, Otto Fuel Loading Schematic. Loading and drumming stations are located along the loop. A plastic orifice gasket located near Building 1461 provides back pressure to effect loading. The design is intended to preclude pumping surges caused by valve closing and pumping against a closed system.

The transfer pump was located at the top of the formulation tank as originally installed. A second pump had been installed to filter sodium carbonate and other residues resulting from processing. This system recirculated the fuel in the formulation tank thru an Alsop filter for a time period that had been found to provide sufficient filtering. The pump was the closed can type in which a portion of the pumped fluid provides cooling by being circulated thru the bearings and around the rotor of the electric motor.

In normal operations, contents of the formulation tank are pumped out to a low level limit. This provides air entry into the transfer line thru the return leg in the tank. Another source of air is the blowdown operation used to clear the hose from the transfer line to tank trucks at that loading station.

The transfer line is sloped to provide for drainage. After a transfer operation, the tank outlet valve is left open for a timed period to allow for drainage but not with the intent of completely draining the line.

INCIDENT

On 30 May 1979, at the instant the filtering pump was remotely turned off by an operator, a "pop" noise was heard. Operators evacuated the area, as smoke was observed coming from the building. Approximately 17 minutes later, an explosion occurred in the Otto Fuel transfer pipeline near Building 1513. Damage to the transfer line and the building are shown in Figure 3, Damage to Building 1513. There were approximately 60 pipe fragment holes in the building. Note the 17 minute time delay. It is important to comprehending the potential hazard detected in investigation of this incident.

Without a complicating factor, the incident would have been over with the original "pop" noise which investigation revealed to be rupture of the filtering pump. The complicating factor was that the building fire protection flapper valve (main valve) did not open although the detection system functioned normally and the Fire Department responded and had been on the scene several minutes when the second or pipeline explosion by Building 1513 occurred. Water pressure records and tests establish that the sprinkler valve did not function on the initial explosion. It did open at the time of the second explosion and suppress the fire in Building 1463. Apparently, shock forces transferred by the pipeline from the second explosion site by Building 1513 back into Building 1463 broke loose whatever was restraining the flapper valve.

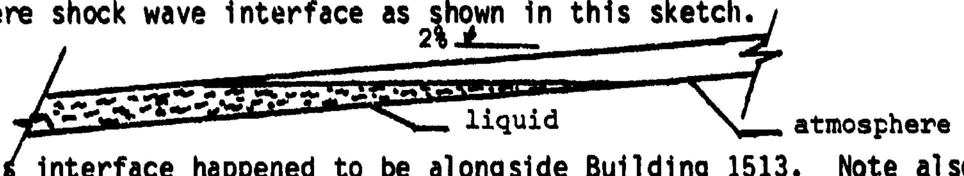
The fire protection system and flapper valve had been wet-tested in April (2 months prior) without any indication of potential failure. It was the opinion of the investigating team that corrosion or mechanical linkage binding in the the valve or solenoid was the cause of the flapper valve failure to open. Subsequent function testing could not detect or create any condition which would cause the flapper valve to stick closed. Had the flapper valve opened, the incident would have been relatively minor.

INVESTIGATION FINDINGS

Evidence indicates that the initial explosion in Building 1463 occurred because of overheating of Otto Fuel II in the filtering pump bearing coolant loop. The overheating was probably a result of a combination of factors. These were paper causing blockage of the pump impeller creating some rotor imbalance with bearing heating and reduced flow by loading of the sodium filter.

The pump ruptured by ejection of the back plate and rotor as shown in Figure 4, Otto Fuel Filtering Pump. These parts were not completely ejected as they were constrained by the floor. This explosion triggered the fire detection system but as stated a malfuncation did not allow water flow. The fuel ejected and ignited by the explosion was fed by more material draining from the formulation tank. The formulation tank valve closed after an unknown time when the plastic air line providing pressure to open the valve burned thru allowing spring power closure.

The return leg of the transfer line was near the ceiling of the building (directly above the spilled fuel and fire area. After some time (approximately 17 minutes) of heating, the fuel residue and/or air-fuel vapor atmosphere in the pipeline ignited. It is conjectured that a supersonic shock wave was generated which traveled (refer to Figures 1 and 2) up the return leg of the transfer line and down the pump leg (up and down refers to slope of the transfer line) until it struck the liquid fuel held in the line by the transfer pump. The shock wave, increased or maintained by decomposition of residuals in the pipeline, caused explosive decomposition at the liquid-atmosphere shock wave interface as shown in this sketch.



This interface happened to be alongside Building 1513. Note also that the day was unusually warm and the pipeline was subjected to solar heating possible increasing the fuel vapor concentration. Evidence to support the described scenario of the second or pipeline explosion is:

a. Fragments of the plastic orifice gasket in the pipeline by Building 1461 were found at the pipe rupture site. Refer to Figures 1 and 2 to comprehend the route these fragments had to travel. (The schematic does not show two 90° radius turns that had to be negotiated).

b. Direction of pipe rupture and fragment travel an unconsumed fuel spray.

c. Length of ruptured pipe corresponds with length of liquid-atmosphere interface in the sloping pipe as shown in the sketch above.

d. Otto Fuel remained in the pipeline from a few feet from the rupture back to the transfer pump.

e. Residues in the atmosphere (empty upslope section) and liquid/filled sectionsof the pipes at the rupture site were different. The residue in the atmosphere section showed evidence of some burning and contained decomposition products. The liquid leg residue was normal.

Further investigations into the phenomenas in this incident are being conducted. Initiation mechanisms, conditions of pipeline interior supporting decomposition transfer, and temperature conditions are major areas being studied.

Other than that fuel decomposed by the shock vave at the interface, the liquid phase fuel did not react explosively. The liquid which spilled on the ground from the ruptured pipe at Building 1513 and on the floor from the pump in Building 1463 burned quietly.

The significance of this incident is that a pipeline containing Otto Fuel residuals on the surface and air-fuel vapor atmosphere apparently can be ignited by external fire, and possibly create and transfer a shock wave.

Installations should be reviewed for the potential hazard this transfer might create. It does not appear that the liquid fuel is subject to large scale initiation as the pipeline return leg is thought to have carried the shock wave into the formulation tank without ignition of contents. However, the fact that Otto Fuel vapor/air atmosphere in a pipeline can be ignited and transfer an energetic shockwave is a subtle hazard which should be considered in each installation involving this monopropellant.

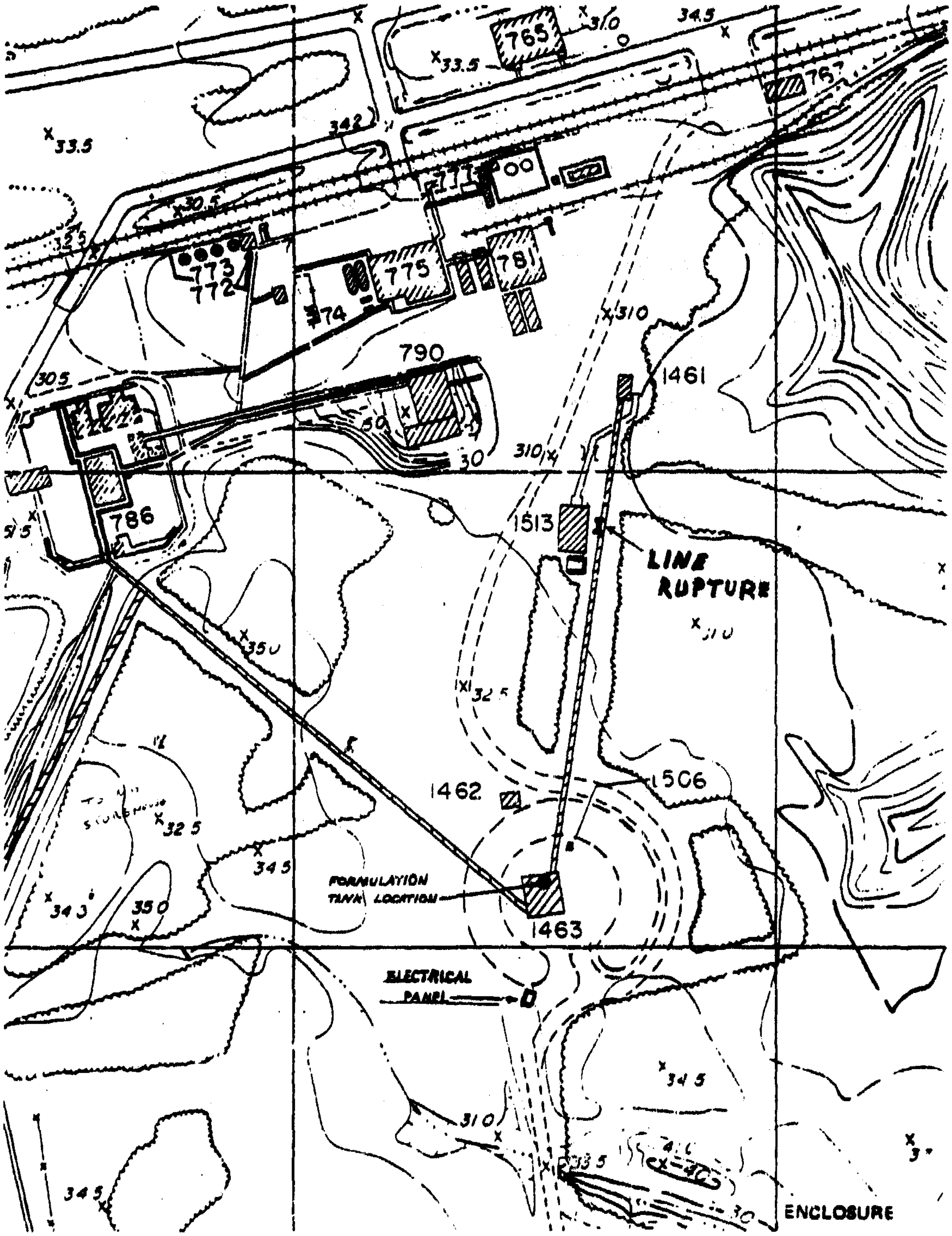


Figure 1. NITRATION FACILITY

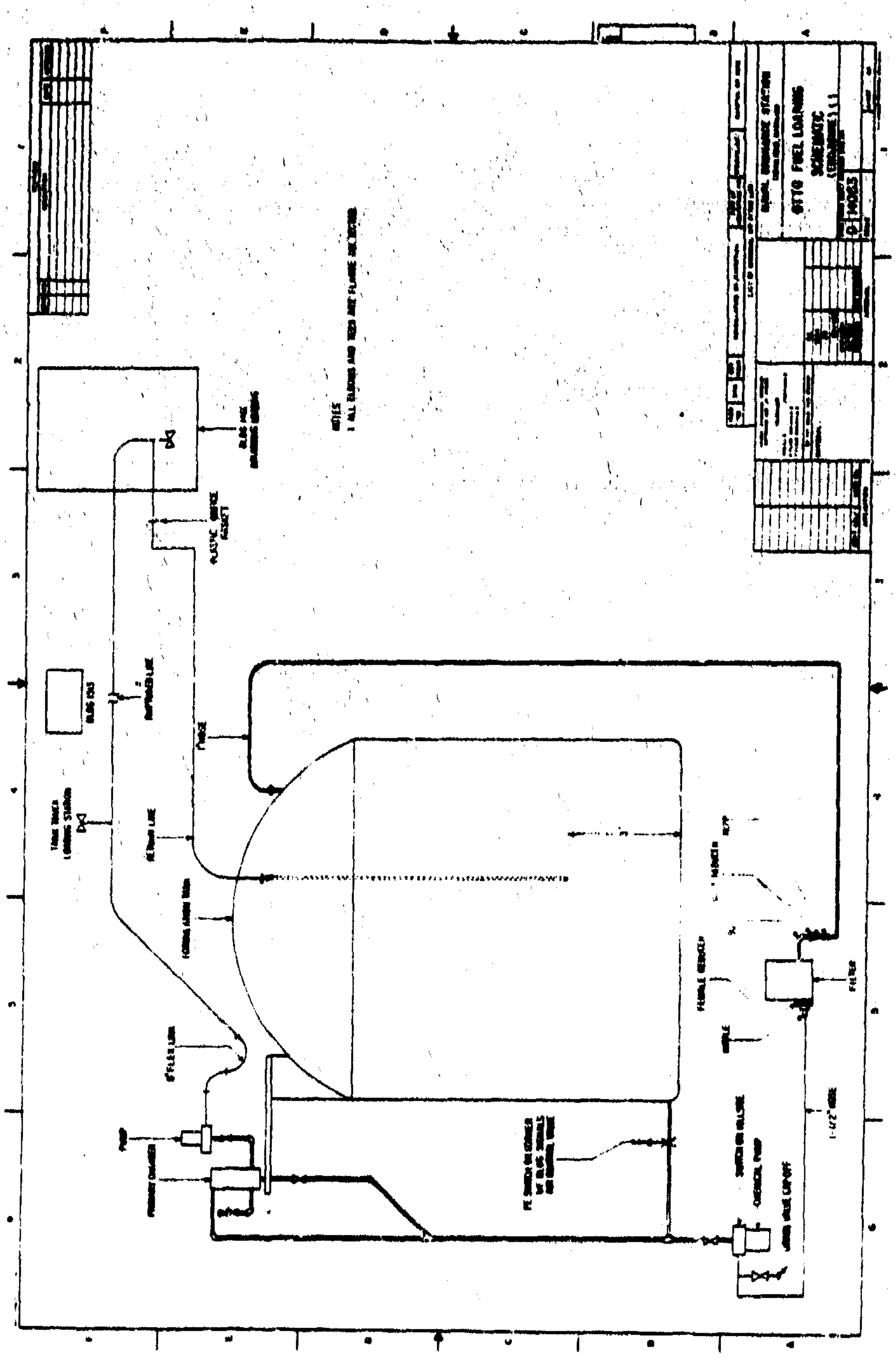


Figure 2. OTTO FUEL LOADING FACILITY

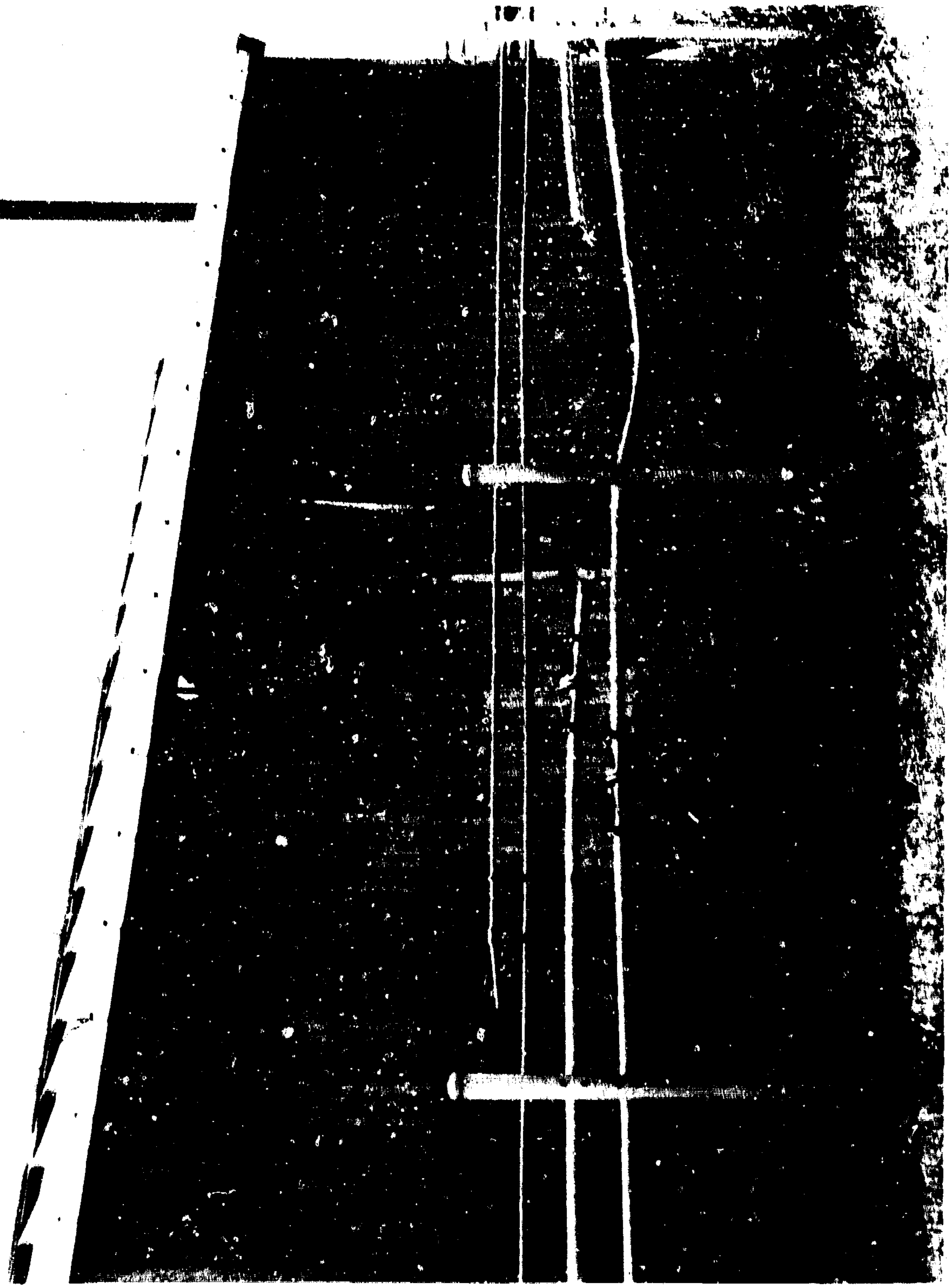


Figure 3. DAMAGE TO BUILDING 1513

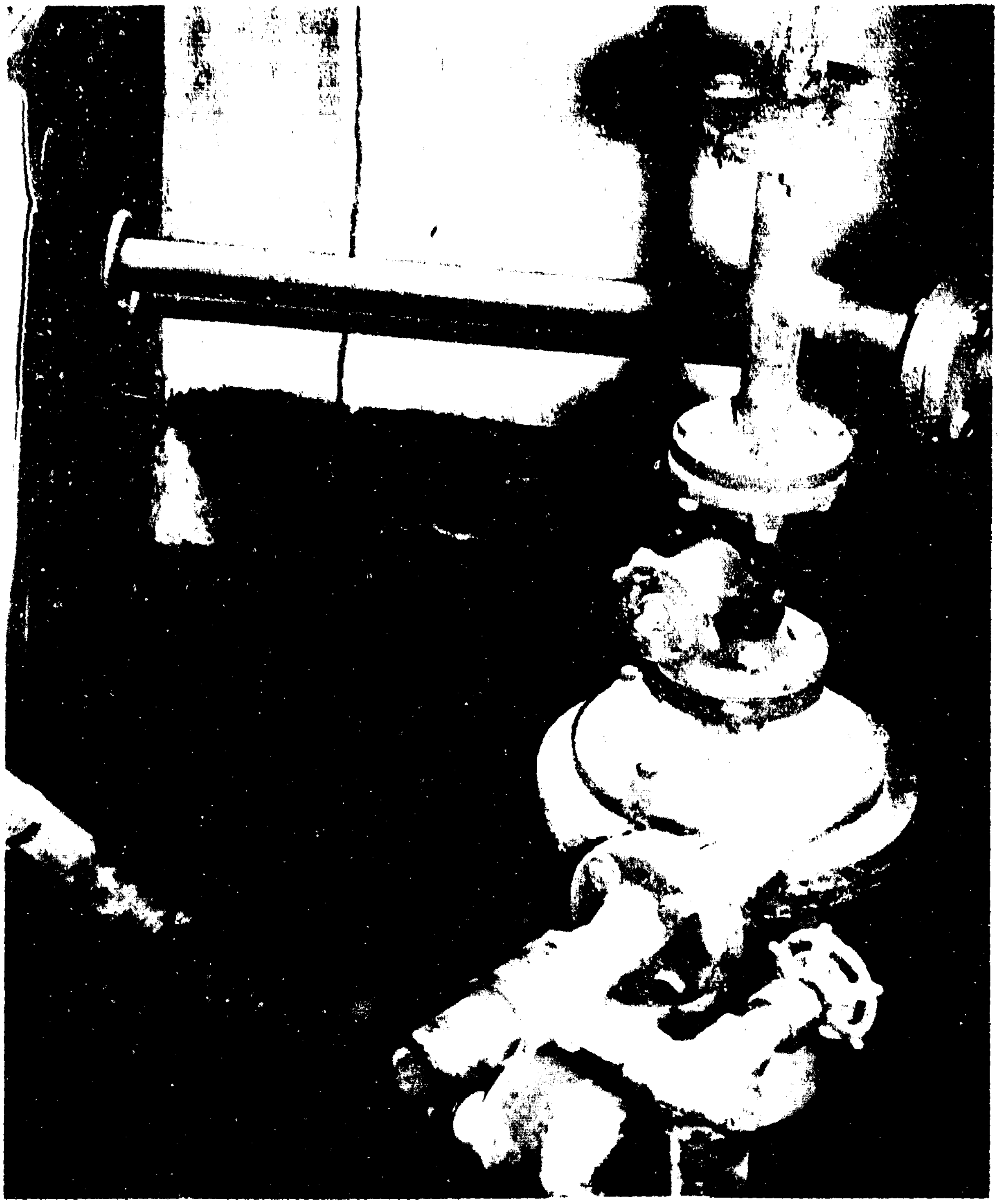


Figure 4. OTTO FUEL FILTERING PUMP

LONGHORN ARMY AMMUNITION PLANT
PYROTECHNIC MIXING ACCIDENT

I. INTRODUCTION

Good afternoon, my name is Ray Fatz; I work with the US Army Armament Materiel Readiness Command at Rock Island, Illinois.

I was a member of the Army Board of Investigation that was convened to determine the cause of the pyrotechnic accident at Longhorn Army Ammunition Plant, Marshall, TX (Figure 1), and to develop recommendations to prevent its recurrence. The bottom line of an accident investigation is to identify the most probable cause. As everyone in the explosives business knows, this task is never easy, and in some cases is even impossible. In this accident, much of the evidence was destroyed and the only person who knew exactly what happened was killed. It is impossible to be 100 percent certain that the true cause was identified. However, after what was a difficult, long, and arduous investigation, the Board made its "best guess."

A point I want to make early in this presentation, and one I want you to keep in mind as I go through the process description and the investigation process is the many events and circumstances which had to be present and synchronized for this accident to occur.

II. BACKGROUND

On 7 January 1980, at approximately 11:30 am, a fire occurred in Bays C and D of Building B11 while mixing the ALA-17 flare composition.

The incident resulted in the death of one operator and injury to another, the loss of two 158 pound ALA-17 mixes, damage to the building and a temporary loss of production capability. (Figure 2)

The ALA-17 mix consists of atomized magnesium, nitrocellulose, teflon, and acetone. (Figure 3)

III. DESCRIPTION OF MIXING PROCESS

A brief description of the mixing process may be appropriate at this time. (Figure 4) The first step is for the operator to pour the pre-weighed magnesium through a screen into the Muller type Simpson mixer. (Figure 5) Then the nitrocellulose is poured uniformly over the magnesium.

The two mixing bays are then evacuated, the operators close an interlocked door and retire to the remote control station. (Figure 6) The mixer is then remotely operated for 5 minutes.

(Figure 7) After this mixing cycle, the operators enter their mixing bays and a blender bucket of pre-weighed teflon is poured through a screen and spread by hand uniformly over the mix.

The bays are evacuated and the mixers are again operated for 5 minutes. Acetone is added during this cycle and subsequent mixing cycles anytime that the mix appears to be drying out.

After each remote mixing cycle, the operators enter their bays to manually check the mix and to scrape down the mixer. The mixing cycles are repeated until the mix has reached a damp, sandy consistency similar to putty or dough. If the material is too wet at the end of 20 minutes of mixing, the mix cycle may be lengthened in 1 to 2 minute increments until the required consistency is obtained.

When the material has reached the desired consistency, then approximately 30 pounds of material is remotely dumped into buckets until all material is discharged.

The illuminant composition is then tray dried until suitable for granulation. After granulation, the composition is again tray dried prior to the pressing operation.

IV. EVENTS LEADING UP TO THE INCIDENT

On the day of the incident, at 0850, the first two mixes of the day began. The operators were having difficulty in achieving the correct mixture consistency. The mixing cycle for the two mixes was longer than usual. (Figure 8) The addition of the final mix ingredient, teflon, was completed about 0930.

The particle size of the magnesium was finer than the magnesium used in the past. The fine particle size required the addition of more acetone than normally required to properly distribute the nitrocellulose binder and the teflon oxidizer - 23,000 cc of acetone was added to the mix in Bay C and 16,000 cc to the mix in Bay D.

After the teflon was added, the mixers were remotely operated in 2 minute cycles to dry the mix to the correct consistency. During the drying cycles an exhaust hood is normally placed over the mixer to aid in the removal of acetone vapors.

At 1125 the two operators went to their adjacent but separate bays to check their mixes with the QC inspector. It was determined that the mix in Bay D was properly mixed and ready to dump. The mix in Bay C required an additional drying cycle. The operators returned to the control panels to remotely dump approximately 30 pounds of mix into a bucket in Bay D and remotely operate the mixer in Bay C to complete the drying routine. Shortly before 1129, the operators went to the mixing bay area.

(Figure 9) This viewgraph depicts a similar mixer and clothing worn by an operator.

The Bay C operator went to the bay to check the mix. The Bay D operator was having a minor problem with the aluminized hood snaps and entered Bay D a few seconds after the operator entered Bay C.

The Bay D operator entered the bay - checked the dump bucket and heard a scream immediately followed by a loud noise - looked up and saw a flash from the vicinity of Bay C and a fireball filling the hallway. The Bay D operator ran through the fireball and out the emergency doors to the service road 80 feet to the rear of the building. (Figure 10)

When the operator reached the road (Figure 11) and turned to see if the operator in Bay C made it out, the mix in Bay D ignited.

Figure 12 is a close-up view of the mixer discharge chute and the remains of the blender bucket.

Figure 13 shows the damage in Bay D.

Figure 14 is the aluminized suit and hood worn by Bay D operator.

The fire activated the HAD deluge system and triggered the fire alarm at the Longhorn Fire Station. Fire department personnel entered the building and found the body of the Bay C operator in the hall outside Bay C (Figure 15). The body was found face down and head pointed toward the Bay D emergency door (Figure 16). The aluminized hood was off and between the body and Bay C. Figure 17 shows the operator hood and approximate distance from the mixer. The firemen checked for life signs; all were negative. The operator received burns to the head, neck, arms, hands and lower extremities. The probable cause of death, as determined by a doctor, was inhalation of smoke and flash fire affecting the respiratory system to a massive enough extent to precipitate a cardiac arrest. The next two viewgraphs illustrate the extensive damage of the aluminized hood (Figures 18 and 19).

The operator in Bay D received first and second degree burns of the hands and lower extremities.

V. THE ACCIDENT INVESTIGATION

After notification of the accident, an ARRCOM Accident Investigation Board was immediately appointed to investigate the facts and circumstances pertaining to the accident.

I will now briefly describe the investigation process which led to determining the most probable cause. This viewgraph illustrates the areas investigated by the Board. (Figure 20)

From a process and physical standpoint, the accident involved three distinct areas; the mixing bays (C and D) and the rotoclone vapor and dust collector (Figure 21). The first priority was to determine in which of these areas the incident most likely initiated in order to narrow the search for the most probable cause.

Bay D was easily eliminated, since the Bay D operator stated that the fire did not originate in Bay D and there was less fire damage to the bay. This was because the deluge system in Bay D activated shortly after the fire traveled to the Bay D mixer.

Figure 22 is a photograph showing the rotoclone after the accident. Note the missing door which blew off and landed on the roof of Bay C. This indicated that there was an explosion in the rotoclone. The Board was then faced with the question of, did the rotoclone ignite first and cause Bay C to ignite or did Bay C ignite and cause the rotoclone to ignite.

The exhaust and ventilation systems were thoroughly examined (Figure 23). There was 100 percent make-up to the bays with humidity automatically controlled to 70-80°F, and 50 to 60 percent relative humidity. Exhaust is provided through a vapor/dust collector, known as the rotoclone, with a hood for the mixer during mixing (Figure 24) and an automatic diverter near the ceiling to remove bay air when the hood is not being used. The hood is covered with conductive plastic sheet designed to melt quickly and not interfere with extinguishment. The hood is manually placed and removed.

After pulling all the available information together, the Board determined that the rotoclone was not the area of initiation. This determination was based on the following (Figure 25):

There was soot on the outside of the bay side rotoclone door. This door was found on the roof of Bay C lying upside down. One of the door dogs which was broken off was found in the gutter of Bay C with soot on it.

If the fire had started in the rotoclone, there would be no soot on the outside of the door or the dog. A witness also stated that he saw smoke and fire from the building before he heard the rotoclone blow. A complete teardown of the rotoclone system revealed no electrical or mechanical abnormalities. The Board concluded that the pressure burst of the rotoclone was caused by an acetone air mixture initiated by fire from Bay C.

By the process of elimination, Bay C was determined to be the area of initiation. With this conclusion, the searth for a probable cause was narrowed to operations and potential initiation stimuli available within Bay C.

The initiation stimuli were separated into three main categories: Acts of God, equipment failure, and human factors (Figure 26).

Acts of God were ruled out (Figure 27). There were no weather conditions which could have initiated or contributed to the incident. Operator illness; i.e., blackout, heart attack, convulsions, etc. can in no way be completely excluded as causing or contributing to the accident. However, the operator's past medical history and recent health condition, as reported by the plant doctor and fellow employees, did not indicate any operator illness.

A security investigation revealed that sabotage was not involved in the incident.

Equipment failure was then considered by the Board. All equipment, both inside and outside the bays were checked after the fire. (Figure 28) A complete teardown of all the equipment revealed that there were no conditions that would indicate any of the equipment had an electrical short, or being probable contributors to the incident. (Figure 29) The Bay C mixer was connected to power and operated with a simulated load after the incident to evaluate mechanical aspects of the mixer. There were no unusual noises or heat build up observed. No unusual foreign material was discovered in or around the mixer. When the mixer was operated, it functioned as designed. (Figure 30). The fire protection system was a dual-automatic sprinkler type with fusible head and dry pipe deluge open heads and pneumatic rate of rise actuating device. A standard heat lamp test indicated a reaction time of 3 to 5 seconds. A thermostatic detector was placed above each mixer to automatically stop the mixers and ventilation system if a fire occurred. (Figure 31). Human factors were then considered as an initiation stimulus.

After interviewing other mixer operators and walking through the mixing process many times, the Board narrowed down the possible initiating stimulus to friction, impact, and static discharge, and the events which could have precipatated the stimuli.

Scrapedown was eliminated since both the Bay C and D scrapers were found intact. Figure 32 shows the position of a scraper as found outside Bay D emergency door.

Figure 33 is a closeup of the scrapers recovered outside the emergency doors. The scraper on the left was found outside Bay C. If the fire was started by friction created by the scraper, the illuminant, and the mixer: there would have been a significant burn spot on the scraper (Figure 34). Results of microscopic evaluation of the scraper material indicated the scraper to be composed of a phenolformaldehyde resin. Lab tests revealed the presence of magnesium particles and that the scraper is insoluble in acetone, the melting point is greater than 662°F and burns at 600°F in muffle furnace. As a reference point, the ALA-17 mix burns at approximately 5000°F.

The most probable area of impact was determined to be the operator dropping the exhaust hood and hitting mix on the wheel or edge of mixer. This was eliminated since the investigation revealed that the exhaust hood was not used during the mixing cycle. Figure 35 shows the hood hanging on the wall. The burn and soot patterns indicate that the hood was on the wall during the fire.

Again by process of elimination, it was determined that the most probable initiation stimuli was static discharge from the operator.

The clothing worn by the Bay C operator was significant in steering the investigation to static discharge as the initiation stimuli. Figure 36 describes the clothing worn by the Bay C operator. The operator was wearing an aluminum coat and hood, Nomex coveralls, nylon undergarments, nylon stockings, cotton socks, conductive shoes, and rubber gloves.

Lab tests (Figure 37) were conducted to identify clothing fibers. Microscopic examination of the socks showed material to be composed of cotton.

A solubility test of the hose indicated nylon. With the aid of a magnifying glass and microscope, the labels revealed two pieces of undergarments to be 100 percent nylon. This was also substantiated by a solubility test.

Tests were conducted in a similar mixing bay using a person of similar stature to determine if a static electric charge could be generated and detected on the body of a person under various conditions of clothing.

Tests to determine if static electric charge could be generated and detected on body of person under various conditions of clothing. (Tests were conducted in Bldg B-12).

Materials:

1. Static meter-Sweeney #1125 (qualitative, comparative reading only).
2. Nomex coveralls, cotton underwear and socks as issued by change house to production workers.
3. Aluminum coat and hood as used in B-11.
4. Conductive sole shoes.
5. Rubber gloves (Playtex).
6. Nylon underwear and stockings.

Conditions:

1. Conductive floor.
2. Shoes checked before and after tests.
3. Movements intended to generate static charge, although not unrealistic to original condition in B-11; walking, stretching, brief rubbing of arms, shoulders, chest, hips.

Static Electric Charge Tests

Test #1

With Nomex coveralls
Rubber gloves
Conductive sole shoes
Cotton Socks
Nylon underwear
Nylon stockings

Results: Strong reading into red area on scale in areas of underwear. Variant readings in red over all of body. No reduction within 2 minutes.

Test #2

As in Test #1 but without nylon stockings.

Results: Slight indication within green area of scale around underwear, reduction to zero within 20 seconds.

Test #3

With Nomex coveralls
Shoes
Cotton socks
Nylon underwear
Aluminum coat and hood
Rubber gloves

Results: No reading over surface of coat or hood, or on legs of coveralls below coat

Test #4

As in Test #3, but with nylon stockings under socks.

Results: No readings on coat, hood, or legs.

Test #5

With Nomex coveralls
Shoes
Cotton socks and underwear
Nylon stockings

Results: Variant readings over body, all within green area of scale.

Test #6

As in Test #5 but without nylon stockings.

Results: No readings.

Test #7

With Nomex coveralls
Shoes
Nylon underwear
Cotton socks
Nylon stockings under cotton socks
Aluminized coat
Rubber gloves

Results: Reading into red area of scale in areas of underwear. Reading into green area of scale over rest of body. No reading outside of coat.

Test Conclusions:

1. Strong static charge can be generated by nylon underwear under coveralls (Test #1); lesser generation under coveralls and aluminized coat (Test #7).

2. Nylon stockings will prohibit dissipation of static charge (compare Test #1 with Test #2; Note Tests 5 and 7).

3. Aluminized coat semi-insulation static charge (Compare Tests 3 and 4 with Test 7) and promotes dissipation (Compare Test 7 with Test 1).

4. Slight static charge generated with cotton underwear, detectable buildup with nylon stockings (Test 5), undetectable with cotton socks (Test 6).

5. Qualitative nature of static readings does not allow comparisons of these test data with electrical ignition sensitivity data from other sources.

6. Further testing required.

A number of circumstances made it possible for static electricity to ignite the mix (Figure 43). (1) Nylon is an excellent generator of static charges and an extremely poor conductor of these charges, (2) Nylon worn on a person's body isolated from ground can build up significantly, (3) Test results of'a similarly dressed person measured more than 800 volts existing on the surface of the coveralls, (4) Nylon socks can effectively insulate a person from ground, (5) The instantaneous discharge of a charge would generate enough energy to ignite an explosive mixture of air and acetone vapor or the ALA-17 illuminate mix and, (6) Tests conducted revealed that the nylon socks inhibited the draining off of a static charge.

The determination that the initiation stimulus was static electricity still left the Board with the question of what was the source of initiation. Two media were present that static electricity could have initiated - acetone vapor or the ALA-17 mix.

Records of chemical analysis conducted on the mix ingredients prior to mixing revealed the following (Figure 44):

Magnesium: By use of Fisher sub sieve particle size was determined to be below spec requirements. The requirement was for a 14-22 micron particle size; however, the actual size was 5 to 6 microns. Nitrocellulose and teflon were accepted based on lab results and certificate of analysis. The acetone was accepted based on a certificate of compliance (Figure 45). The Board had two types of magnesium tested. The 5 to 6 micron size and magnesium used in previous mixes. The test results revealed that the 5 to 6 micron magnesium was more spark sensitive than a larger particle size magnesium. Test results showed that it would take .016 joules to ignite the 5 to 6 micron magnesium as compared to .04 joules for the larger size magnesium.

The remains of the mix in the mixer was analyzed after the accident and no unusual foreign material was found in the mix. It was quite obvious that the mix ignited, but to determine if static electricity ignited the mix first, or acetone vapors then the mix is impossible to conclude; however, acetone vapors was the most probable media. Figure 46. The conclusion that static discharge was the most probable initiation stimuli and that the acetone vapors were the most probable initiation media is substantiated as follows: (1) As a rule of thumb, the human body can easily build up a static charge energy of 20 milli-joules. (2) Minimum ignition energy for acetone and air is 1.15 milli-joules. (3) Clothing worn by the operator could easily build up a static charge. (4) Nylon stockings worn by the operator prohibited dissipation of static charge, and (5) Acetone was not exhausted from the mixer since the exhaust hood was not used.

After all the collected data and analysis were pulled together, the Board determined that a combination of circumstances led to the creation of static electricity in a flammable environment. Figure 47 illustrates the number of contributing factors associated with this accident: (1) Finer particle size magnesium, (2) Ventilation system, (3) Protective clothing, (4) Procedures, (5) Fire suppression system, (6) Exhaust hood, (7) Nylon clothing, (8) Hands-on operations, (9) Increased use of acetone and, (10) Static electricity. All these factors, either directly or indirectly had an effect on the accident.

Keeping all this in mind, the Board developed various scenarios to determine how and why the accident occurred. I will now briefly explain our best guess at what happened. The operator went into Bay C to manually check the mix consistency. The process of putting on the aluminized coat over the Nomex coveralls and the movements to the bay coupled with the nylon undergarments resulted in a static electricity build up sufficient enough to ignite the acetone in the mixer. There is a strong possibility that acetone was present in the mixer since the exhaust hood, which was very large and cumbersome was not used, and there was more acetone used in this particular mix than previously used. A major reason for the increase in acetone was the use of a new finer particle size magnesium.

When the operator reached into the mixer to check the mix the bare skin exposed at the wrist, due to the use of short rubber gloves, which were used because with the aluminized gloves, which were required, the operators could not feel the mix, or the aluminized suit came close enough to the side, the wheel, or other portion of the mixer to permit a substantial electrical discharge from the body to ground through the mixer. This electrical discharge lit the acetone vapors above the mix, the operator screamed, and then the 158 pounds of the ALA-17 illuminant mix ignited. The fireball traveled to Bay D and ignited that mix and at about the same time traveled through the duct work to ignite the acetone vapors in the rotoclone.

Recommendations were developed by the Board to prevent recurrence of a similar accident. Briefly the recommendations were: (1) Install TV cameras such that mixing action and discharge into buckets can be observed remotely, (2) Install rapid response deluge system utilizing UV sensors, (3) Extend a

side vent to floor for removal of acetone vapors, (4) Redesign mixer exhaust system to eliminate placing and removing the hood, (5) Initiate a system to check employees for proper conductivity, (6) Insure compliance with written procedures, (7) Insure adequate procedures, (8) Install acetone sensors to determine when an explosive mixture of air and acetone is present in the bay and, (9) Wear aluminized gloves during pyrotechnic mixing operations.

These recommendations were immediately implemented at the production facility. When the Accident Investigation Board formally adjourned, the investigation was completed. However, ARRCOM has continued to investigate new methods and equipment to improve pyrotechnic operations throughout the DoD production base.

DOD CONVENTIONAL AMMUNITION PRODUCTION BASE GOVERNMENT OWNED FACILITY LOCATIONS

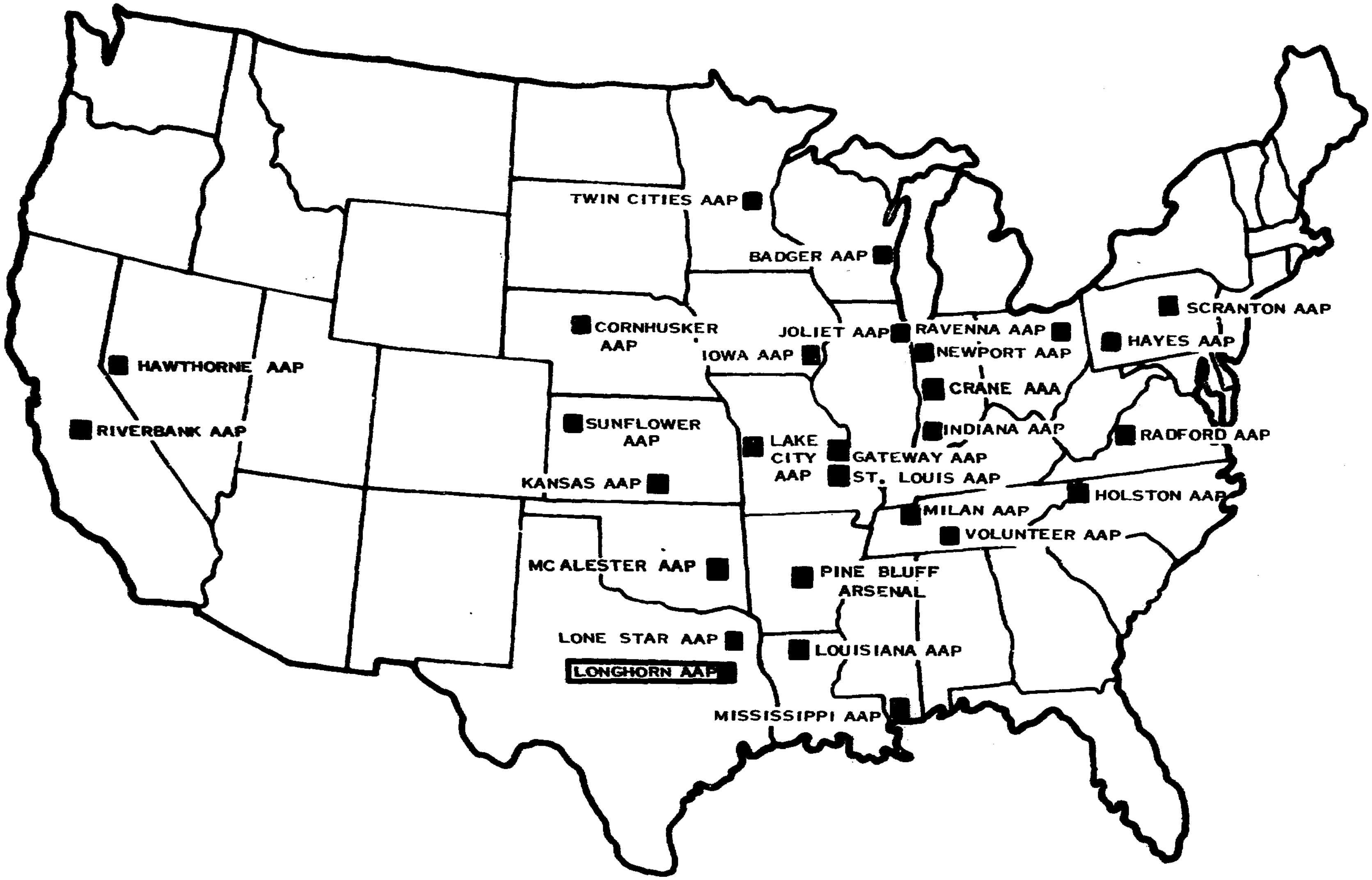


FIGURE 1

INCIDENT STATISTICS

7 JANUARY 1980

- KILLED ONE PERSON, INJURED ONE PERSON
- TWO 158 LB ALA-17 MIXES LOST
- DAMAGE TO BUILDING
- LOST PRODUCTION CAPABILITY

FIGURE 2

ALA-17 FLARE COMPOSITION

- TOTAL WEIGHT OF MIX WAS APPROXIMATELY 158 LBS.
  - ATOMIZED MAGNESIUM
  - NITROCELLULOSE
  - TEFLON
  - ACETONE
- EXACT WEIGHT OF MIX INGREDIENTS IS CLASSIFIED.

FIGURE 3

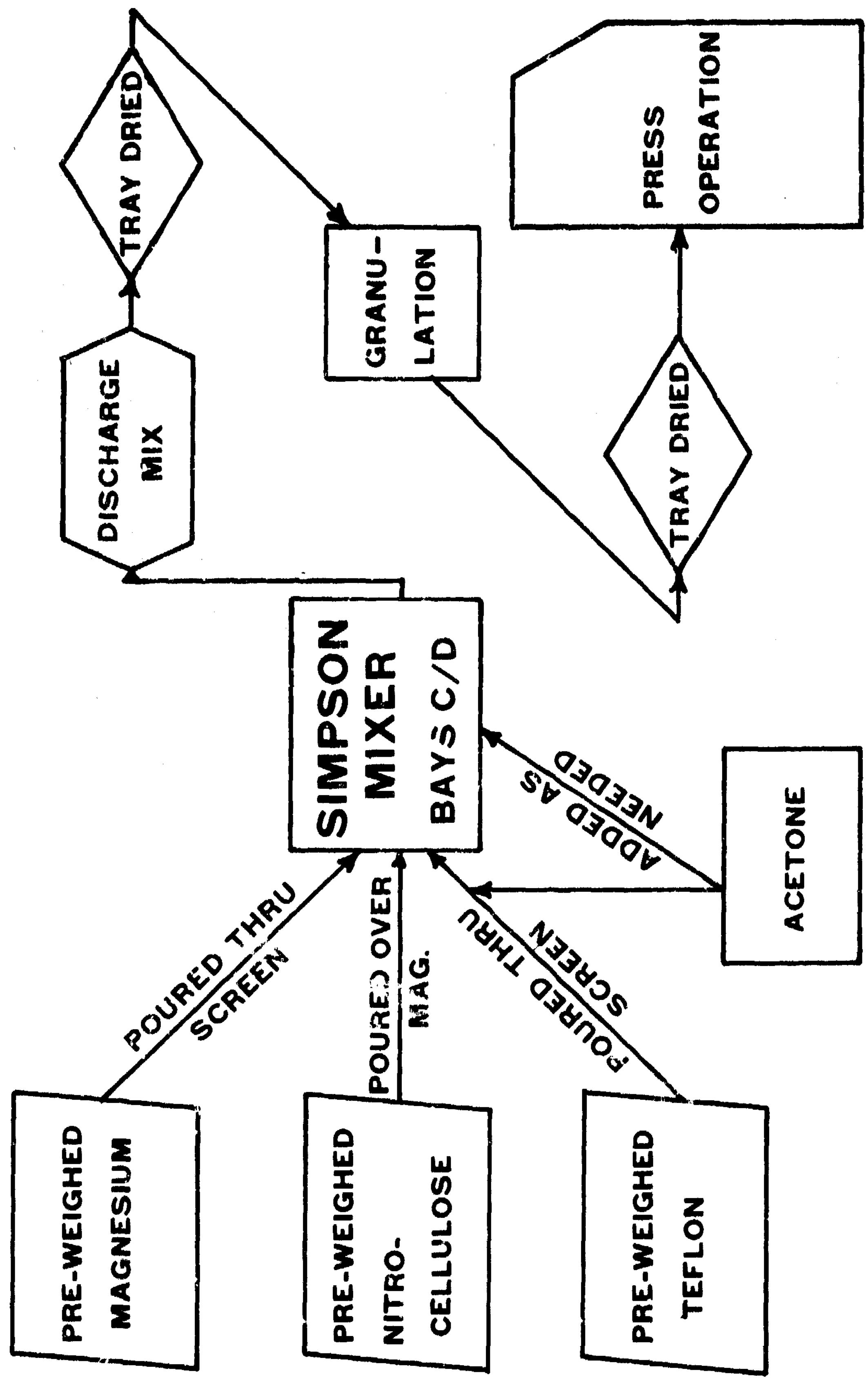
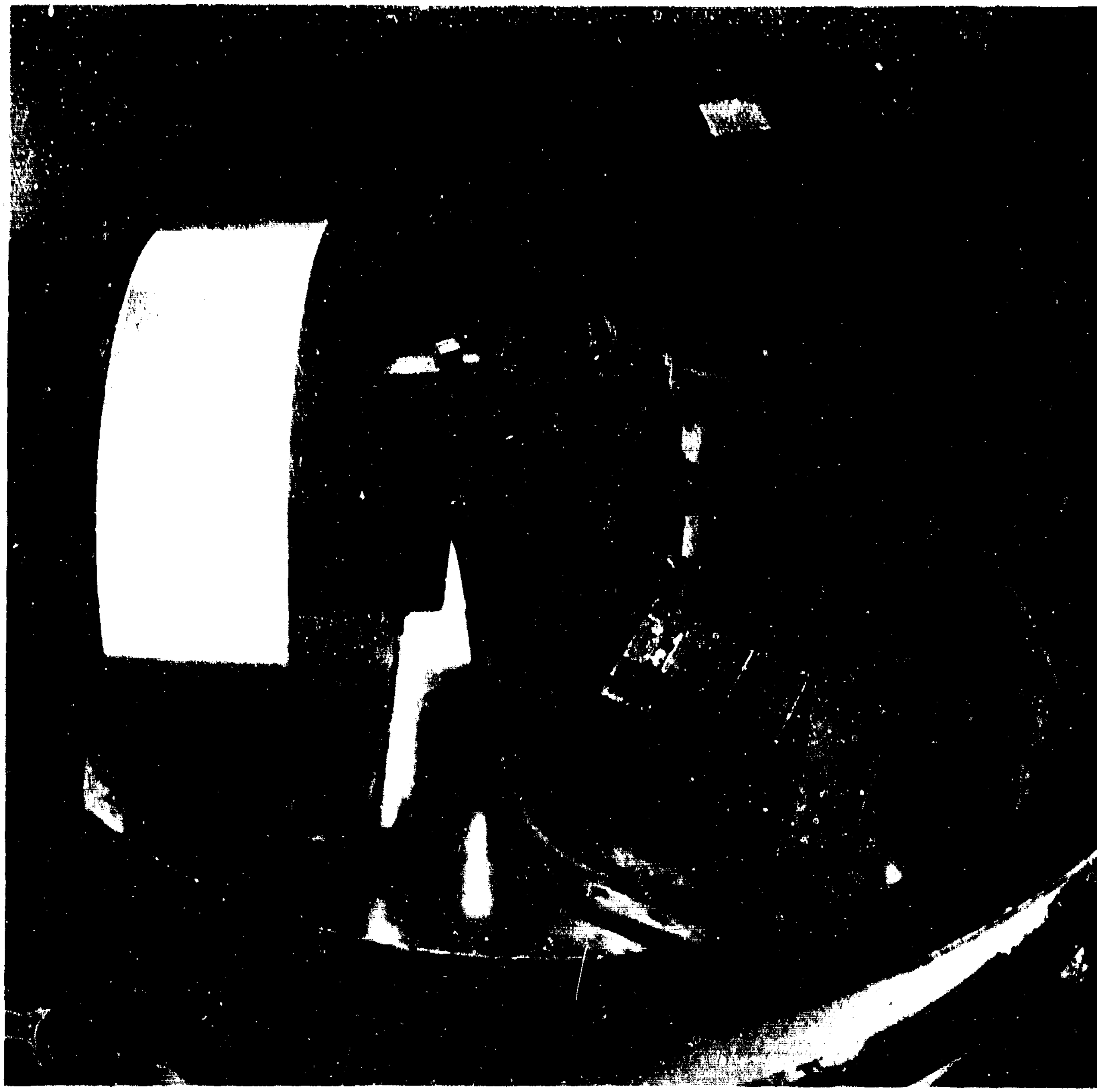
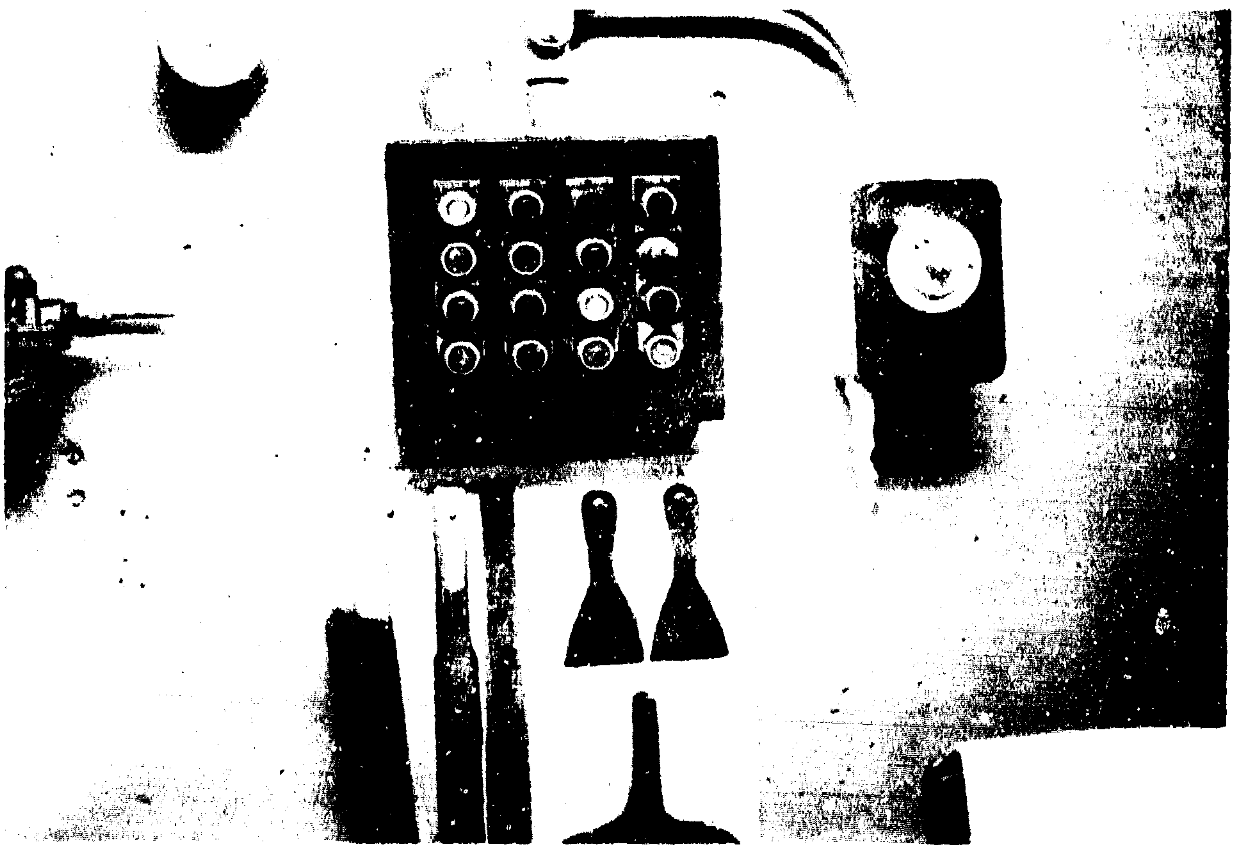

PRE-WEIGHED MAGNESIUM
PRE-WEIGHED NITRO-CELLULOSE
PRE-WEIGHED TEFLON
POURED THRU SCREEN
POURED OVER MAG.
POURED THRU SCREEN
ACETONE
ADDED AS NEEDED
SIMPSON MIXER BAYS C/D
DISCHARGE MIX
TRAY DRIED
GRANU-LATION
TRAY DRIED
PRESS OPERATION

FIGURE 4



VIEW OF SIMILAR MIXER WITH MULLER WHEEL AND PLOW BLADE (FOREGROUND) PRIOR TO LOADING OF MIX.

FIGURE 5



CONTROL PANEL AND TOOL BOARD FOR BAY C, LOCATED IN EAST CORRIDOR OF BUILDING B-11. NOTE TWO EMPTY HOOKS FOR SCRAPERS (SILOUTTE OF OLD STYLE PROFILE).

FIGURE 6

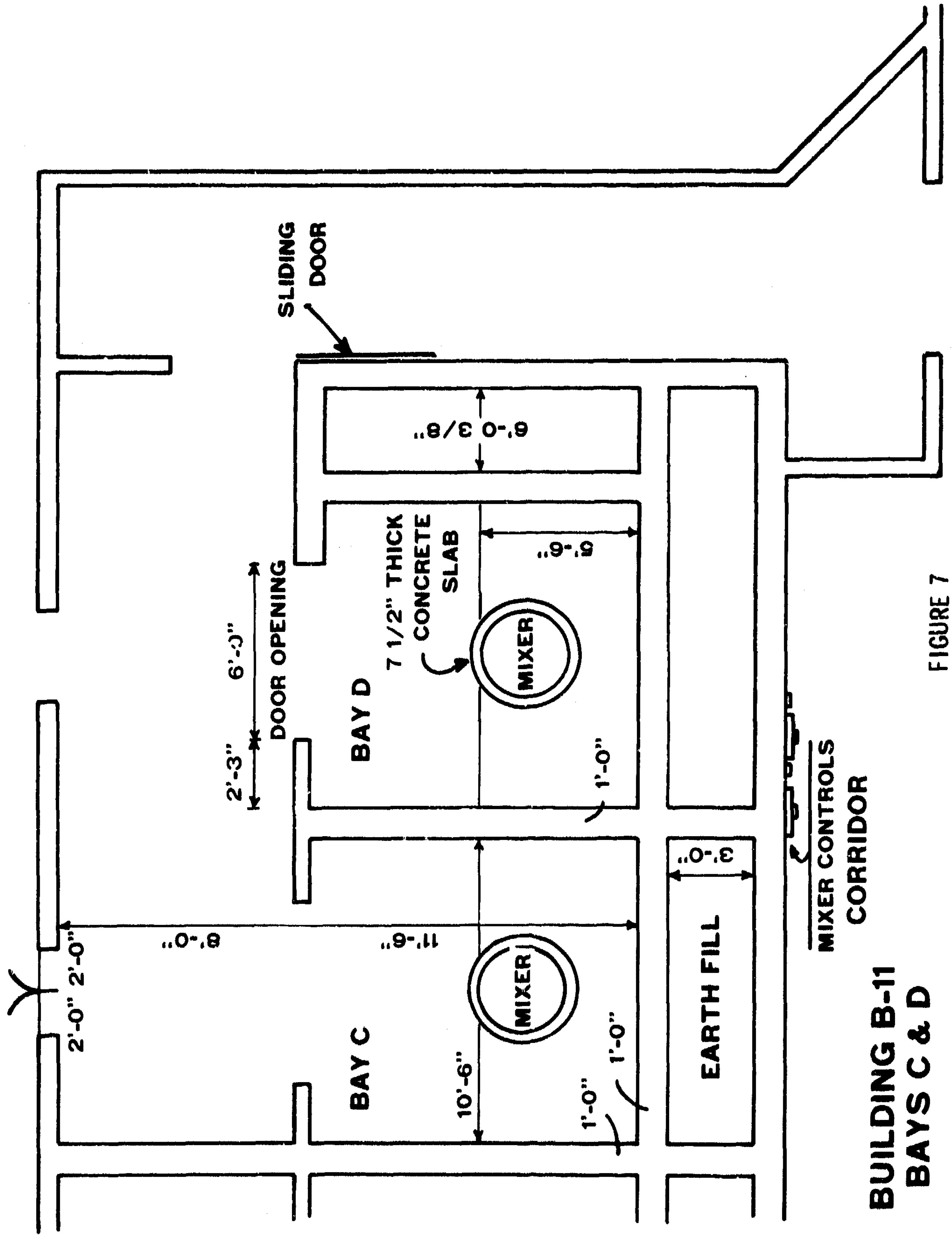

BUILDING B-11
BAYS C & D
SLIDING DOOR
6'-0 3/8"
5'-6"
7 1/2" THICK CONCRETE SLAB
MIXER
BAY D
DOOR OPENING
6'-0"
2'-3"
1'-0"
BAY C
MIXER
8'-0"
11'-6"
10'-6"
2'-0" 2'-0"
1'-0"
1'-0"
EARTH FILL
3'-0"
MIXER CONTROLS
CORRIDOR

FIGURE 7

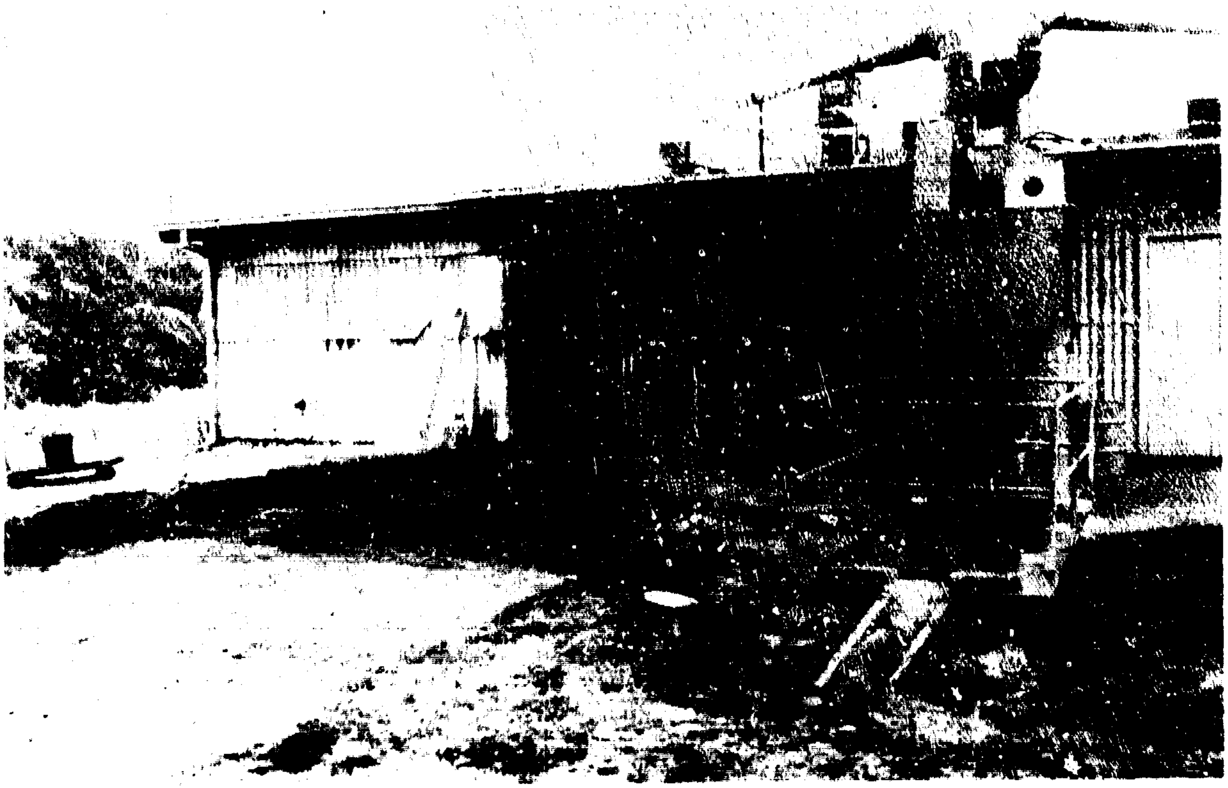
PREVIOUS B-11 ALA-17 MIXES

DATE	BAY	START	STOP	ACETONE
2 JAN 80	C	1046	1157	12,000 CC
2 JAN 80	D	1046	1157	9,000 CC
3 JAN 80	C	0848	1010	
3 JAN 80	D	0848	0953	
4 JAN 80	C	0831	0917	8,000 CC
4 JAN 80	D	0831	0947	8,000 CC
5 JAN 80	C	0830	0925	8,000 CC
5 JAN 80	D	0830	0925	
5 JAN 80	C	1037	1130	11,000 CC
5 JAN 80	D	1037	1208	
▶ 7 JAN 80	C	0850		23,000 CC <
▶ 7 JAN 80	C	0850	1126	16,000 CC

FIGURE 8

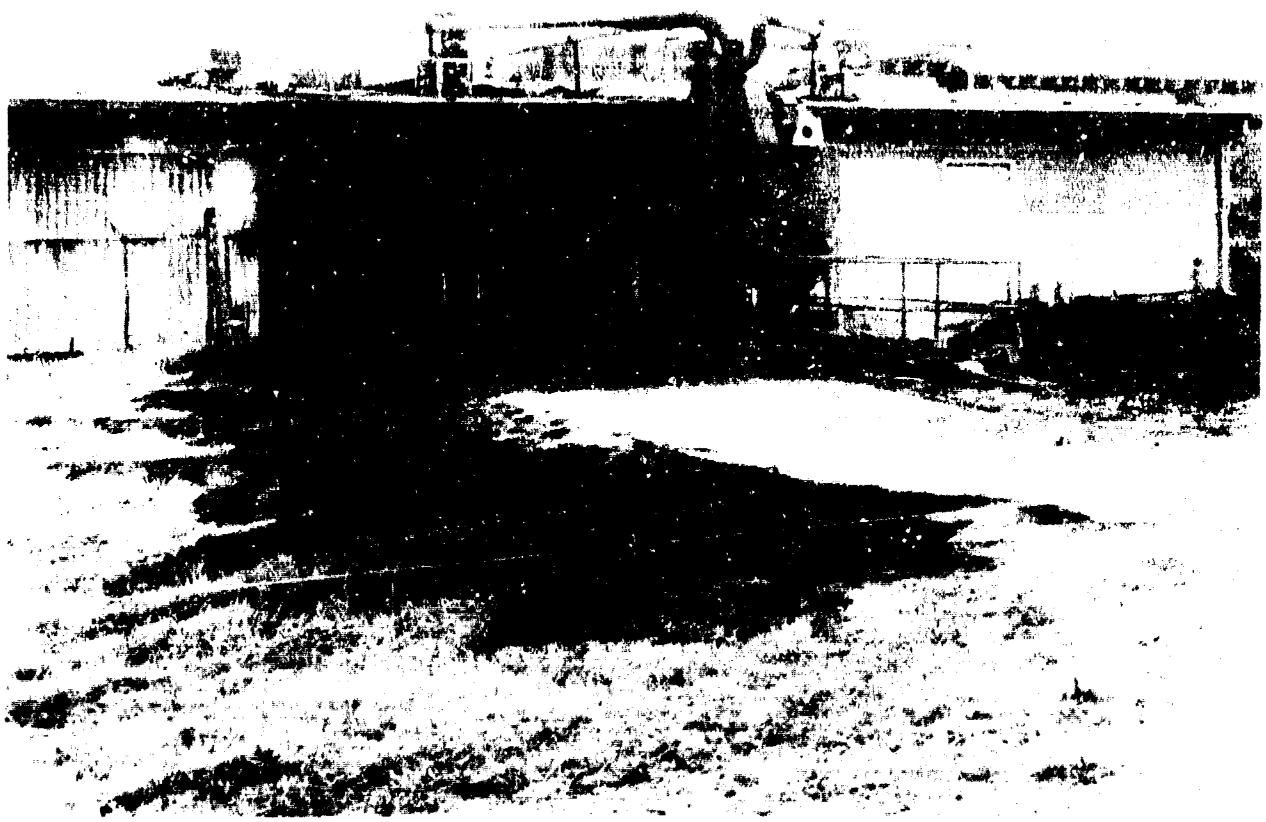
SIMILAR MIXER SHOWING PERSPECTIVE OF OPERATOR APPROACHING FROM LEFT SIDE. MODEL IS APPROXIMATE STATURE OF BAY C OPERATOR.

FIGURE 9



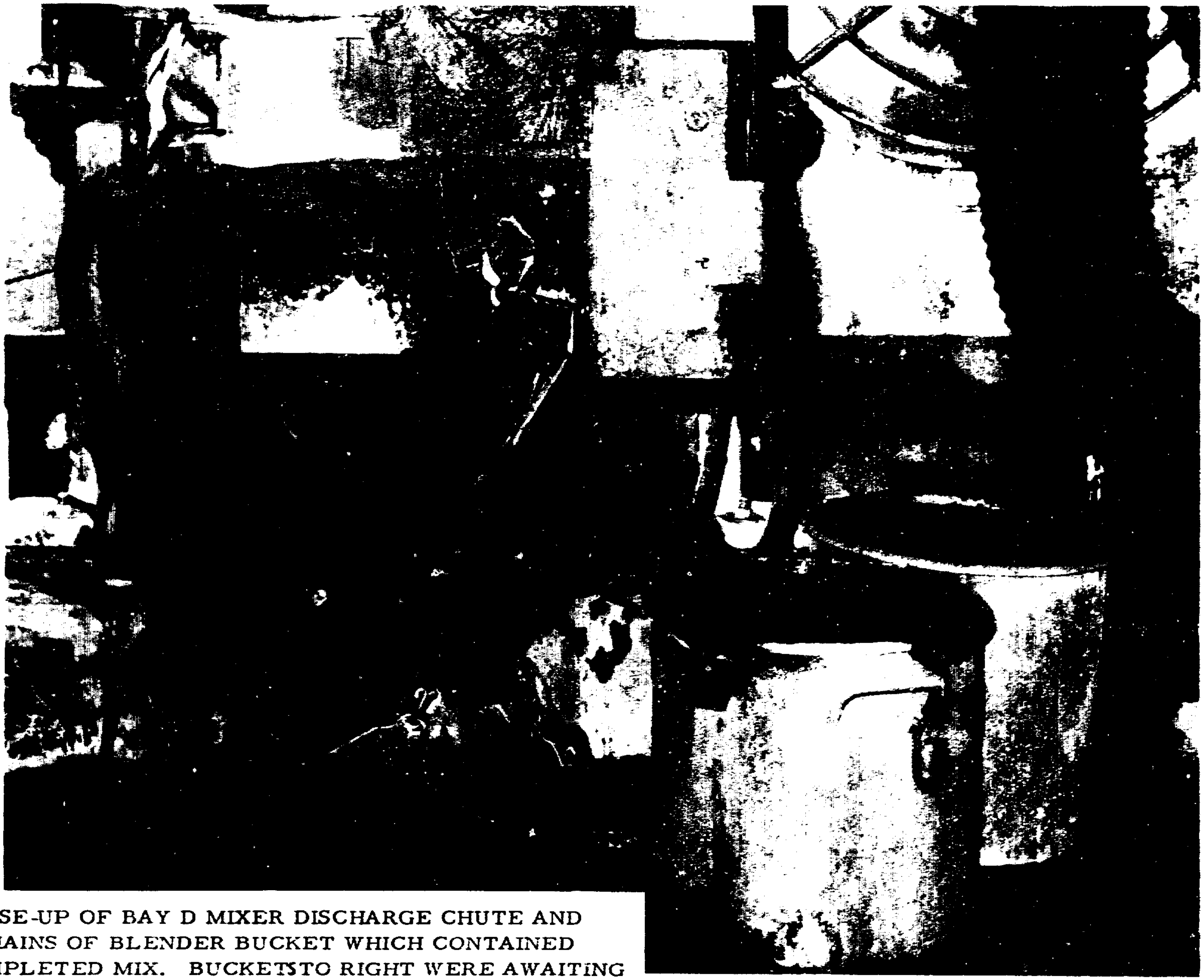
BUILDING B11. BAY C EMERGENCY EXIT AT CENTER, BAY B TO RIGHT, BAY D TO LEFT.

FIGURE 10



BUILDING B11 LOOKING SOUTHEAST FROM SERVICE ROAD.

FIGURE 11



CLOSE-UP OF BAY D MIXER DISCHARGE CHUTE AND REMAINS OF BLENDER BUCKET WHICH CONTAINED COMPLETED MIX. BUCKETSTO RIGHT WERE AWAITING PLACEMENT UNDER CHUTE TO RECEIVE MIX.

FIGURE 12

BAY D, LOOKING EAST FROM WEST CORRIDOR.

FIGURE 13

FRONT VIEW OF ALUMINIZED COAT AND
HOOD WORN BY BAY D OPERATOR

FIGURE 14

BAY C LOOKING EAST THROUGH CORRIDOR FROM CONCRETE APRON OUTSIDE EMERGENCY EXIT.

FIGURE 15

WEST CORRIDOR LOOKING SOUTH FROM SLIDING DOOR IN NORTH CORRIDOR. BAY D ENTRANCE IS AT LEFT FOREGROUND. ALUMINIZED HOOD (ARROW) IS OUTSIDE BAY C ENTRANCE.

FIGURE 16

ALUMINIZED HOOD, USED BY BAY C OPERATOR,
LYING OUTSIDE BAY C IN WEST CORRIDOR

FIGURE 17

LEFT SIDE OF ALUMINIZED HOOD WORN BY
BAY C OPERATOR. UPPER LEFT CORNER OF SHIELD
FRAME MELTED AWAY. SOOT COVERED INNER AND OUTER
SURFACES OF SHIELD. FRONT CAPE BURNED OFF.
LEFT SIDE OF REAR CAPE PARTIALLY BURNED.

FIGURE 18

INSIDE OF ALUMINIZED HOOD WORN BY BAY C
OPERATOR, SHIELD REMOVED.

FIGURE 19

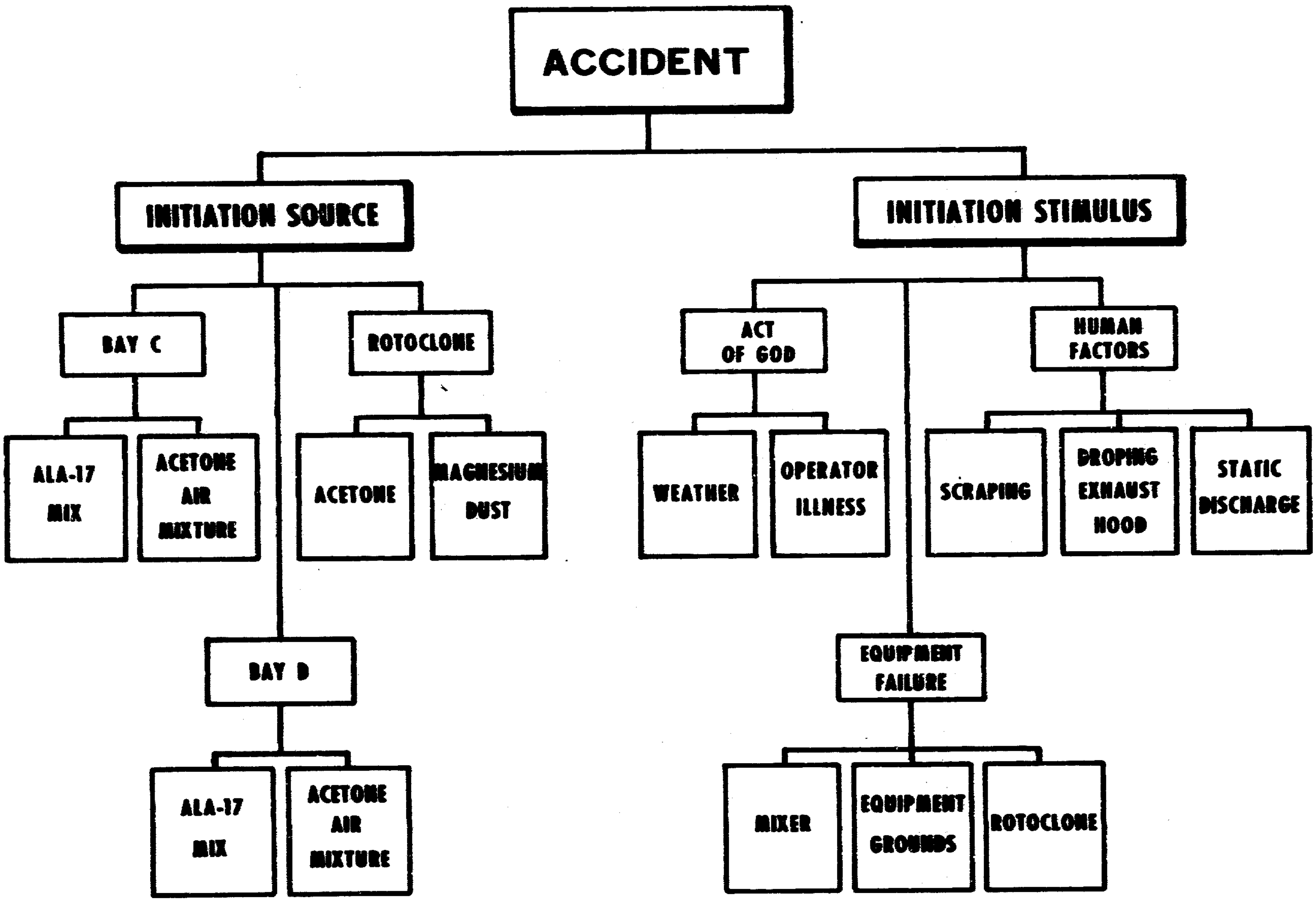
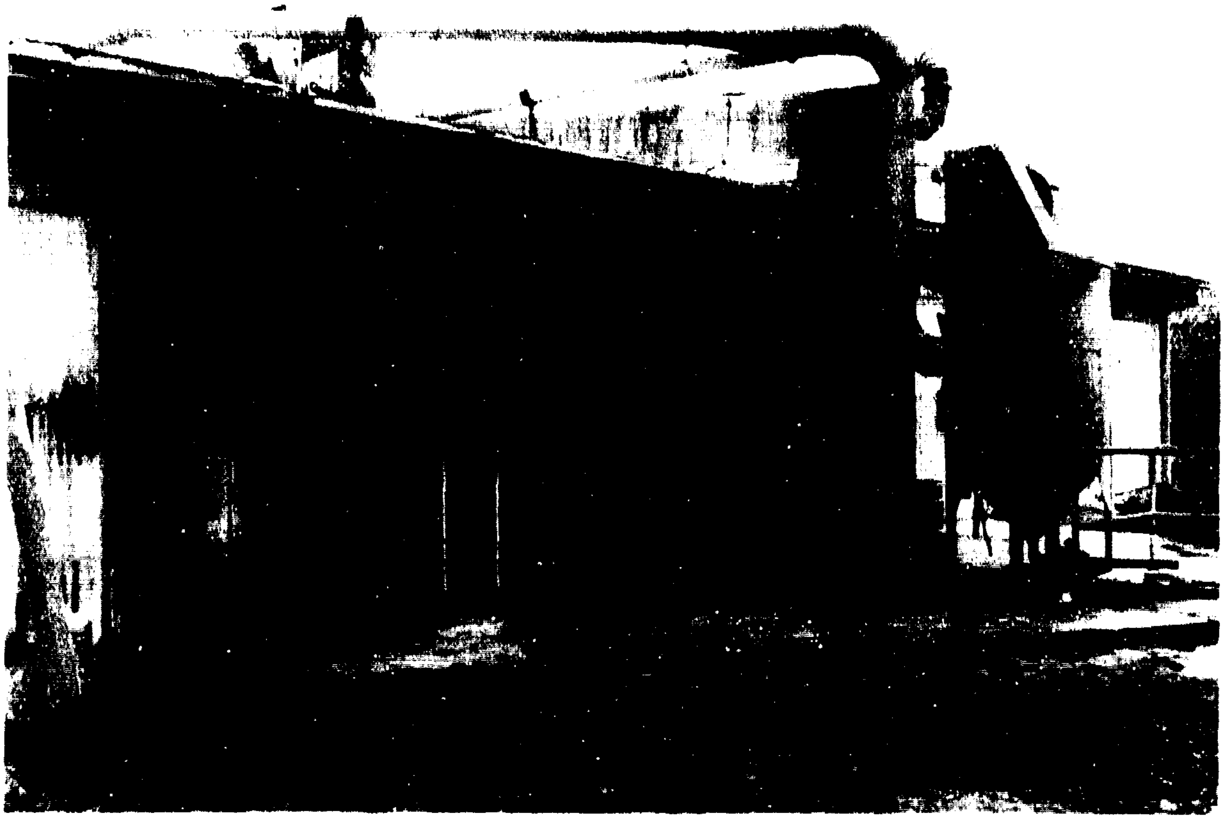

ACCIDENT
INITIATION SOURCE
INITIATION STIMULUS
BAY C
ROTOCLONE
ALA-17 MIX
ACETONE AIR MIXTURE
ACETONE
MAGNESIUM DUST
BAY D
ALA-17 MIX
ACETONE AIR MIXTURE
ACT OF GOD
HUMAN FACTORS
WEATHER
OPERATOR ILLNESS
SCRAPING
DROPING EXHAUST HOOD
STATIC DISCHARGE
EQUIPMENT FAILURE
MIXER
EQUIPMENT GROUNDS
ROTOCLONE

FIGURE 20

POSSIBLE AREAS OF INITIATION

- MIXING BAY D
- ROTOCLONE VAPOR AND DUST COLLECTOR
- MIXING BAY C

FIGURE 21



BUILDING B11. BAY C AND D EMERGENCY EXITS SHOW CHARRING FROM FIRE AND SOOT PATTERN ON CORRUGATED WALL COVERING.

FIGURE 22

EXHAUST AND VENTILATION SYSTEM

- 100% MAKE-UP TO BAY WITH HUMIDITY AUTOMATICALLY CONTROLLED AT 70-80°F, 50-60% RELATIVE HUMIDITY.
- EXHAUST IS PROVIDED THROUGH A VAPOR/DUST COLLECTOR (ROTOCLONE) WITH A HOOD FOR THE MIXER DURING MIXING AND AN AUTOMATIC DIVERTER NEAR THE CEILING TO REMOVE BAY AIR WHEN THE HOOD IS NOT BEING USED.
- THE HOOD IS COVERED WITH CONDUCTIVE PLASTIC SHEET DESIGNED TO MELT QUICKLY AND NOT INTERFERE WITH EXTINGUISHMENT.
- HOOD IS MANUALLY PLACED AND REMOVED.

FIGURE 23

SOUTHEAST CORNER OF BAY C AT CEILING. ROTO CLONE DUCT "Y" IN CENTER, ENVIRONMENTAL SYSTEM VENT AT TOP LEFT AND TEMPERATURE CONTROLS (FOR BAYS C AND D) AT BOTTOM RIGHT. DELUGE HEAD IS JUST BELOW ENVIRONMENTAL SYSTEM VENT; SPRINKLER HEAD IS TO FAR LEFT.

FIGURE 24

REASONS FOR ELIMINATING THE ROTOCLONE AS THE AREA OF INITIATION

- THERE WAS SOOT ON THE OUTSIDE OF THE BAY SIDE ROTOCLONE DOOR. THE DOOR WAS FOUND ON THE ROOF OF BAY C LYING UPSIDE DOWN.
- ONE OF THE DOOR DOGS WHICH WAS BROKEN OFF WAS FOUND IN THE GUTTER OF BAY C WITH SOOT ON IT.
- IF THE FIRE HAD STARTED IN THE ROTOCLONE, THERE WOULD BE NO SOOT ON THE OUTSIDE OF THE DOOR OR THE DOG.
- A WITNESS STATED THAT HE SAW SMOKE AND FIRE FROM THE BUILDING BEFORE HE HEARD THE ROTOCLONE BLOW.
- THE PRESSURE BURST OF THE ROTOCLONE WAS CAUSED BY AN ACETONE AIR MIXTURE INITIATED BY FIRE FROM THE BAY C MIXER.

FIGURE 25

INITIATION STIMULI

- ACTS OF GOD
- EQUIPMENT FAILURE
- HUMAN FACTORS

FIGURE 26

WEATHER CONDITIONS - 7 JANUARY 1980

PROVIDED BY NATIONAL WEATHER SERVICE, SHREVEPORT, LOUISIANA

	10:30 A.M.	11:00 A.M.	12:00 NOON
TEMPERATURE	42^0F	47^0F	42^0F
HUMIDITY	86%	86%	82%
WIND DIRECTION	NW	N	N
WIND VELOCITY	13 MPH	10 MPH	10 MPH, GUST TO 18
BAROMETER	30.05 ↑	30.06 ↑	30.06 STEADY
GENERAL WEATHER CONDITION	CLOUDY & DRIZZLE	CLOUDY	CLOUDY

FIGURE 27

EQUIPMENT FAILURE

- ALL EQUIPMENT, BOTH INSIDE AND OUTSIDE WAS CHECKED AFTER THE FIRE.
    - NO CONDITIONS WERE FOUND THAT WOULD INDICATE ANY OF THE EQUIPMENT HAD AN ELECTRICAL SHORT, OR BEING PROBABLE CONTRIBUTORS TO THE INCIDENT.

FIGURE 28

ELIMINATING THE MIXER MECHANISM AS THE CAUSE OF THE ACCIDENT

- THE BAY C MIXER WAS CONNECTED TO POWER AND OPERATED WITH SIMULATED LOAD AFTER THE INCIDENT TO EVALUATE MECHANICAL ASPECTS OF THE MIXER.
    - NO UNUSUAL NOISES OR HEAT BUILD UP WAS OBSERVED.
    - NO UNUSUAL FOREIGN MATERIAL WAS DISCOVERED IN OR AROUND THE MIXER.
    - THE MIXER FUNCTIONED AS ORIGINALLY DESIGNED.

FIGURE 29

FIRE PROTECTION SYSTEM IN BAYS C & D

FIRE PROTECTION SYSTEM WAS DUAL-AUTOMATIC SPRINKLER WITH FUSIBLE HEADS AND DRY PIPE DELUGE OPEN HEADS AND PNEUMATIC RATE OF RISE ACTUATING DEVICE.

A THERMOSTATIC DETECTOR WAS PLACED ABOVE EACH MIXER TO AUTOMATICALLY STOP MIXER AND VENTILATION IF A FIRE OCCURED.

FIGURE 30

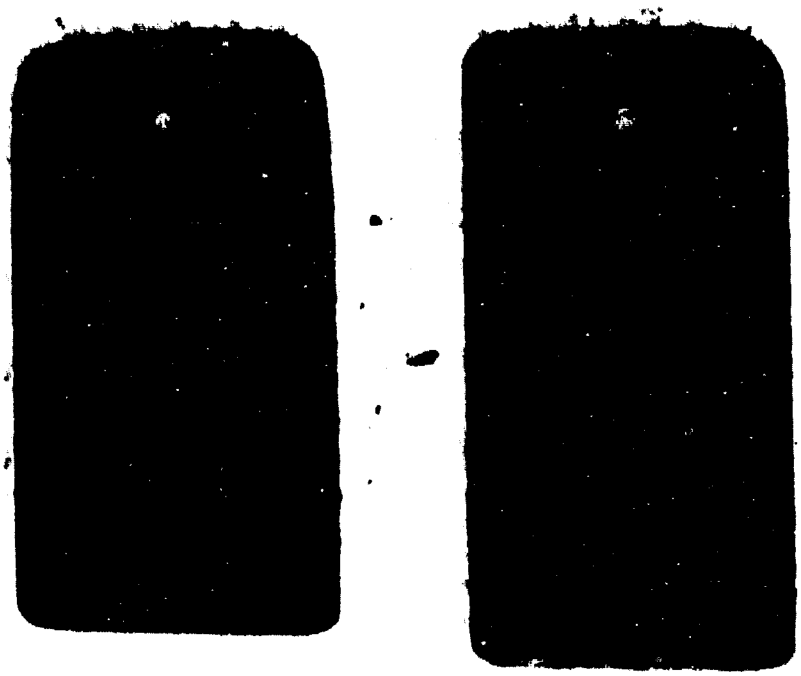
HUMAN FACTORS

- OPERATOR SCRAPING MIX
- OPERATOR DROPING/DRAGGING EXHAUST HOOD
- STATIC DISCHARGE

FIGURE 31

SCRAPER LOCATED IN GRASS OUTSIDE BAY D EMERGENCY EXIT DOOR.

FIGURE 32



CLOSEUP OF SCRAPERS RECOVERED OUTSIDE EMERGENCY EXIT DOORS. LEFT SCRAPER FOUND OUTSIDE BAY C.

FIGURE 33

SCRAPER

- RESULTS OF MICROSCOPIC EVALUATION OF SCRAPER MATERIAL INDICATE SCRAPER TO BE COMPOSED OF A PHENOLFORMALDEHYDE RESIN.
- THE PRESENCE OF MAGNESIUM PARTICLES WAS NOTED.
- SCRAPER MATERIAL:
  - INSOLUBLE IN ACETONE, METHYLENE CHLORIDE, TOLUENE, AND ETHANOL.
  - MELTING POINT GREATER THAN 662^{0}F.
  - BURNS AT 600^{0}F IN MUFFLE FURNACE.

FIGURE 34

BAY C LOOKING EAST FROM WEST CORRIDOR. NOTE EMPTY BLENDER BUCKET BELOW CLOSED DISCHARGE CHUTE.

FIGURE 35

CLOTHING WORN BY BAY C OPERATOR

- ALUMINUM COAT AND HOOD
- NOMEX COVERALLS
- NYLON UNDERGARMENTS
- NYLON STOCKINGS
- CONDUCTIVE SHOES
- RUBBER GLOVES
- COTTON SOCKS

FIGURE 36

IDENTIFICATION OF CLOTHING FIBERS

SOCKS — MICROSCOPIC EXAMINATION SHOWED MATERIAL TO BE COMPOSED OF COTTON.

HOSE — SOLUBILITY OF SAMPLE IN 20% HYDROCHLORIC ACID SOLUTION INDICATES NYLON.

UNDERGARMENTS—WITH THE AID OF A MAGNIFYING GLASS AND A MICROSCOPE THE LABELS REVEALED TWO PIECES OF UNDERGARMENTS TO BE 100% NYLON. ALSO SUBSTANTIATED BY SOLUBILITY TEST.

FIGURE 37

- TESTS TO DETERMINE IF STATIC ELECTRIC CHARGE COULD BE GENERATED AND DETECTED ON BODY OF PERSON UNDER VARIOUS CONDITIONS OF CLOTHING. (TESTS WERE CONDUCTED IN BLDG B-12)

  - MATERIALS:

    1. STATIC METER-SWEENEY #1125 (QUALITATIVE, COMPARIATIVE READING ONLY)
    2. NOMEX COVERALLS, COTTON UNDERWEAR AND SOCKS AS ISSUED BY CHANGE HOUSE TO PRODUCTION WORKERS.
    3. ALUMINUM COAT AND HOOD AS USED IN B-11
    4. CONDUCTIVE SOLE SHOES.
    5. RUBBER GLOVES (PLAYTEX)
    6. NYLON UNDERWEAR AND STOCKINGS.

  - CONDITIONS:

    1. CONDUCTIVE FLOOR.
    2. SHOES CHECKED BEFORE AND AFTER TESTS.
    3. MOVEMENTS INTENDED TO GENERATE STATIC CHARGE, ALTHOUGH NOT UNREALISTIC TO ORIGINAL CONDITION IN B-11; WALKING, STRETCHING, BRIEF RUBBING OF ARMS, SHOULDERS, CHEST, HIPS.

FIGURE 38

STATIC ELECTRIC CHARGE TESTS

TEST #1

WITH NOMEX COVERALLS

RUBBER GLOVES

CONDUCTIVE SOLE SHOES

COTTON SOCKS

NYLON UNDERWEAR

NYLON STOCKING

- RESULTS: STRONG READING INTO RED AREA ON SCALE IN AREAS OF UNDERWEAR. VARIANT READINGS IN RED OVER ALL OF BODY. NO REDUCTION WITHIN TWO MINUTES.

TEST #2

AS IN TEST #1 BUT WITHOUT NYLON STOCKINGS.

- RESULTS: SLIGHT INDICATION WITHIN GREEN AREA OF SCALE AROUND UNDERWEAR, REDUCTION TO ZERO WITHIN 20 SECONDS.

FIGURE 39

STATIC ELECTRIC CHARGE TESTS
(Continued)

TEST #3

WITH NOMEX COVERALLS

SHOES

COTTON SOCKS

NYLON UNDERWEAR

ALUMINUM COAT AND HOOD

RUBBER GLOVES

- RESULTS: NO READING OVER SURFACE OF COAT OR HOOD, OR ON LEGS OF COVERALLS BELOW COAT.

TEST #4

AS IN TEST #3, BUT WITH NYLON STOCKINGS UNDER SOCKS.

- RESULTS: NO READINGS ON COAT, HOOD, OR LEGS.

TEST #5

WITH NOMEX COVERALLS

SHOES

COTTON SOCKS AND UNDERWEAR

NYLON STOCKINGS

- RESULTS: VARIANT READINGS OVER BODY, ALL WITHIN GREEN AREA OF SCALE.

FIGURE 40

STATIC ELECTRIC CHARGE TESTS
(Continued)

TEST #6

AS IN TEST #5 BUT WITHOUT NYLON STOCKINGS.

- RESULTS: NO READINGS.

TEST #7

WITH NOMEX COVERALLS

SHOES

NYLON UNDERWEAR

COTTON SOCKS

NYLON STOCKINGS UNDER COTTON SOCKS

ALUMINIZED COAT

RUBBER GLOVES

- RESULTS: READING INTO RED AREA OF SCALE IN AREAS OF UNDERWEAR.
  READING INTO GREEN AREA OF SCALE OVER REST OF BODY.
  NO READING ON OUTSIDE OF COAT.

FIGURE 41

STATIC ELECTRIC CHARGE TESTS
(Continued)

▲ **TEST CONCLUSIONS:**

1. STRONG STATIC CHARGE CAN BE GENERATED BY NYLON UNDERWEAR UNDER COVERALLS (TEST #1); LESSER GENERATION UNDER COVERALLS AND ALUMINIZED COAT (TEST #7)

2. NYLON STOCKINGS WILL PROHIBIT DISSIPATION OF STATIC CHARGE (COMPARE TEST #1 WITH TEST #2; NOTE TEST 5 & 7)

3. ALUMINIZED COAT SEMI-INSULATES STATIC CHARGE (COMPARE TEST 3 AND 4 WITH TEST 7) AND PROMOTES DISSIPATION (COMPARE TEST 7 WITH TEST 1)

4. SLIGHT STATIC CHARGE GENERATED WITH COTTON UNDERWEAR, DETECTABLE BUILDUP WITH NYLON STOCKINGS (TEST 5), UNDETECTABLE WITH COTTON SOCKS (TEST 6)

5. QUALITATIVE NATURE OF STATIC READINGS DOES NOT ALLOW COMPARISONS OF THESE TEST DATA WITH ELECTRICAL IGNITION SENSITIVITY DATA FROM OTHER SOURCES.

6. FURTHER TESTING REQUIRED.

FIGURE 42

POSSIBILITIES OF STATIC DISCHARGE
IGNITING THE MIX

- NYLON IS AN EXCELLENT GENERATOR OF STATIC CHARGES AND AN EXTREMELY POOR CONDUCTOR OF THESE CHARGES.
- NYLON WORN ON A PERSON'S BODY ISOLATED FROM GROUND CAN BUILD UP SIGNIFICANTLY.
- TEST RESULTS OF A SIMILARLY DRESSED PERSON MEASURED MORE THAN 800 VOLTS EXISTING ON THE SURFACE OF THE COVERALLS.
- THE NYLON SOCKS CAN EFFECTIVELY INSULATE A PERSON FROM GROUND.
- THE INSTANTANEOUS DISCHARGE OF A CHARGE WOULD GENERATE ENOUGH ENERGY TO IGNITE AN EXPLOSIVE MIXTURE OF AIR AND ACETONE VAPOR OR THE ALA-17 ILLUMINATE MIX.
- TESTS CONDUCTED REVEALED THAT THE NYLON SOCKS INHIBITED THE DRAINING OFF OF THESE CHARGES.

FIGURE 43

CHEMICAL ANALYSIS OF MIX INGREDIENTS USED IN BAY C & D

MAGNESIUM: BY USE OF FISHER SUB SIEVE PARTICLE SIZE WAS DETERMINED TO BE BELOW SPEC REQUIREMENT.

SPEC REQUIREMENT - 14-22 MICRONS
ACTUAL - 5 TO 6 MICRON

NITROCELLULOSE: ACCEPTED BASED ON LAB RESULTS AND CERTIFICATE OF ANALYSIS.

TEFLON: ACCEPTED BASED ON LAB RESULTS AND CERTIFICATE OF ANALYSIS.

ACETONE: ACCEPTED BASED ON CERTIFICATE OF COMPLIANCE.

FIGURE 44

THE BOARD HAD TWO TYPES OF MAGNESIUM TESTED:

	SENSITIVITY IMPACT 4 LB. BALL, NO FIRE, INCHES	FRICTION TEST GRIT BLASTED STEEL, NO FIRE, POUNDS	SPARK SENSITIVITY TEST JOULES, REG. TO IGNITE
● MAGNESIUM PREVIOUSLY USED	11 INCHES	70+	.04+
5 TO 6 MICRON SIZE ● MAGNESIUM AS USED WHEN THE ACCIDENT OCCURED.	11 INCHES	70+	.016

▶ CONCLUSION: THE 5 TO 6 MICRON MAGNESIUM IS MORE SPARK SENSITIVE THAN THE MAGNESIUM USED IN THE PAST.

FIGURE 45

REASONS FOR CONCLUDING THAT STATIC DISCHARGE WAS THE MOST PROBABLE INITIATION STIMULI

- AS A RULE OF THUMB, THE HUMAN BODY CAN EASILY BUILD UP A STATIC CHARGE ENERGY OF 20 MJOULES.
- MINIMUM IGNITION ENERGY FOR ACETONE AND AIR IS 1.15 MJOULES.
- CLOTHING WORN BY THE OPERATOR COULD EASILY BUILD UP A STATIC CHARGE.
- NYLON STOCKINGS WORN BY OPERATOR PROHIBITED DISSIPATION OF STATIC CHARGE.
- ACETONE WAS NOT EXHAUSTED FROM THE MIXER SINCE THE EXHAUST HOOD WAS NOT USED.

FIGURE 46

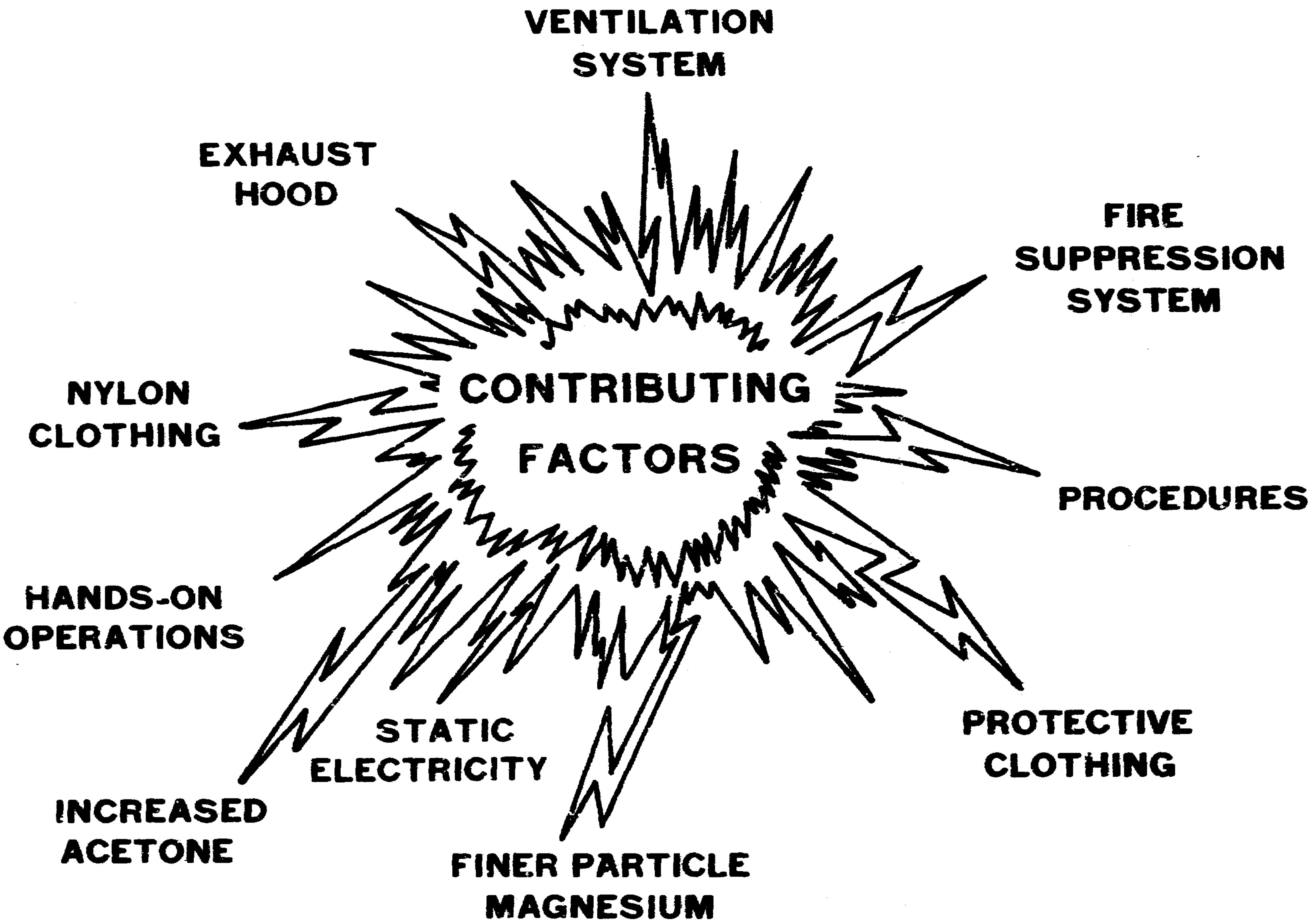

VENTILATION SYSTEM
EXHAUST HOOD
FIRE SUPPRESSION SYSTEM
CONTRIBUTING FACTORS
NYLON CLOTHING
PROCEDURES
HANDS-ON OPERATIONS
STATIC ELECTRICITY
PROTECTIVE CLOTHING
INCREASED ACETONE
FINER PARTICLE MAGNESIUM

FIGURE 47

COMPARISON OF PREDICTIVE METHODS
FOR STRUCTURAL RESPONSE TO
HE BLAST LOADS

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HUNTSVILLE DIVISION
US ARMY CORPS OF ENGINEERS

INTRODUCTION

In designing structures for HE explosions, engineers in the Huntsville Division have readily available numerous technical references. The most frequently used references are the Tri-services Manual TM 5-1300, ASCE Manual 42, Air Force Design Manual, Defense Civil Preparedness Agency's Protective Construction, Huntsville Division's Suppressive Shield Handbook, and Professor Biggs' Structural Dynamics. Other references are either outdated or are currently being developed.

EXAMPLE

To demonstrate the differences, let us look at a few examples. In Figure 1, a reinforced concrete cube is shown subjected to an external and internal HE burst. As shown in Figure 2, three types of loading can be experienced from this arrangement: (1) pressure-time (p-t) single pulse, (2) impulsive, and (3) double pulse. The loadings from the external free air burst are obtained from TM 5-1300 charts and the internal loading is obtained from the Suppressive Shield Handbook charts. These loads are applied on the front wall of the cube with equivalent TNT charge weights and distances as shown on Figure 3. The far-out loading condition, 8,000 lbs at 100 ft., results in a pressure-time (p-t) single triangular pulse, the close-in loading,

512 lbs at 10 ft., is impulsive; and the contained burst, 8 lbs at 5 ft., results in a double pulse consisting of an impulse and a pressure-time (p-t) load. These three loadings are typical in HE explosions.

STRUCTURAL RESPONSE

A reinforced concrete, two-way slab wall (front wall of cube), as shown in Figure 4, is subjected to the three load conditions. The objective is to predict the deflection of the wall by the six methods. The methods mentioned are shown in Figure 5, followed by specific references to equations, tables, etc., for obtaining the necessary properties of the reinforced concrete wall and to obtain the wall deflections. With this information, the property parameters and the deflections were calculated and are shown in the table in Figure 6.

COMPARISON

On quick observation, we see that the parameters obtained are not all necessarily the same. However, it is noted that, for small deflections in the low pressure range, the predicted results are almost the same. For the higher pressure ranges, the deflections using TM 5-1300 and Manual 42 are significantly higher, indicating that these methods are conservative compared to the others.

RATIONALE

Some of the reasons for the conservatism are addressed in the following parameters:

Resistance function. One significant influence for large deflection is a low predicted resistance function (r_u). Figure 7a. shows the yield lines at the two-way slab support. This method, used in TM 5-1300, assumes only half of the negative moments at the perimeter to be fully effective; the other half is two-thirds effective. The other method, shown in Figure 7b., allows the negative moment to be fully effective at the perimeter, giving a higher resistive function.

Moment of inertia. Another contributor is the moment of inertia (I_a). Three different formulas, shown in Figure 8, are often used in calculating moment of inertia (I_a). Based on the thickness of the slab, the differences may be appreciable.

Modulus of elasticity. The modulus of elasticity (E_c) also has an effect. Two formulas, shown in Figure 9, are depicted graphically. When the concrete strength, f_c', is 5,000 psi, the difference in modulus of elasticity is 16 percent.

Stiffness. The successive formation of yield lines on a fixed-edge square slab results in an elastic stiffness, followed by an elasto-plastic stiffness. The use of an equivalent stiffness for these two stiffnesses is the generally accepted practice; however, for simplicity the elastic stiffness alone is sometimes used and results in a very high stiffness. The elastic and elasto-plastic stiffnesses are shown in Figure 10.

TEST PROGRAMS

The predictive methods discussed were all supported by testing of full scale and model structures of steel and reinforced concrete.

Structures were frequently tested to destruction. Notable testing programs were performed for development of TM 5-1300 and the Suppressive Shield Handbook. Generally, test results indicated conservatism in our estimates. Apparently, most of the ductile structural systems have considerably more energy absorbing capability than we expect.

CONCLUSION

Briefly concluding, we may expect that the predictive methods are generally conservative. The methods in TM 5-1300 and Manual 42 appear to be the most conservative. In comparison, the predicted deflection in the low pressure range are not significantly different. However, differences are expected in the higher pressure range.

REFERENCES

1. TM 5-1300: Structures to Resist the Effects of Accidental Explosions, TM 5-1300, Department of the Army, Washington, DC, June 1969.

2. Manual 42: Design of Structures to Resist Nuclear Weapon Effects, ASCE Manual of Engineering Practice No. 42, American Society of Civil Engineers, New York, NY 1964 ed.

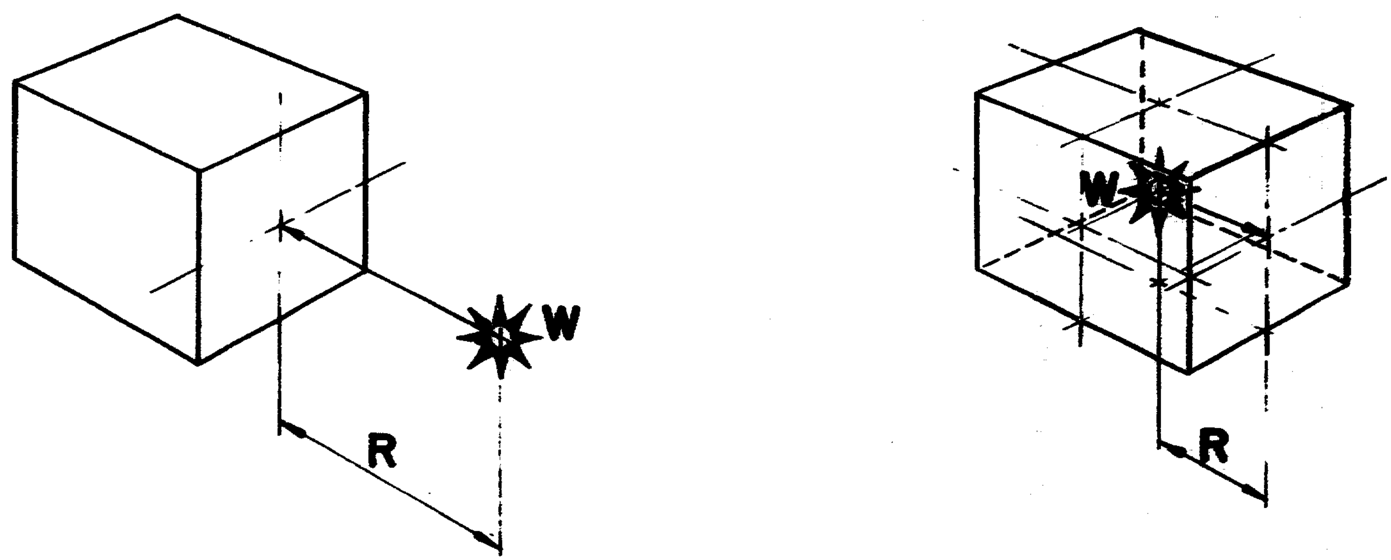
3. AF Manual: Effects of Airblast, Cratering, Ground Shock and Radiation on Hardened Structures, AFSCM Manual 500-8, Department of the Air Force, Washington DC, January 1976.

4. Protective Construction: Protective Construction, TR-20-(Vol 4), Defense Civil Preparedness Agency, Baltimore, MD, May 1977.

5. Suppressive Shield Handbook: Suppressive Shields, Structural Design and Analysis Handbook, HNDM-1110-1-2, US Army Corps of Engineers, Huntsville, AL, November 1977.

6. Biggs: Biggs, J. M., Introduction to Structural Dynamics, McGraw-Hill Book Company, New York, NY, 1964.

LOADING



FREE AIR BURST

CONTAINED BURST

FIG. 1

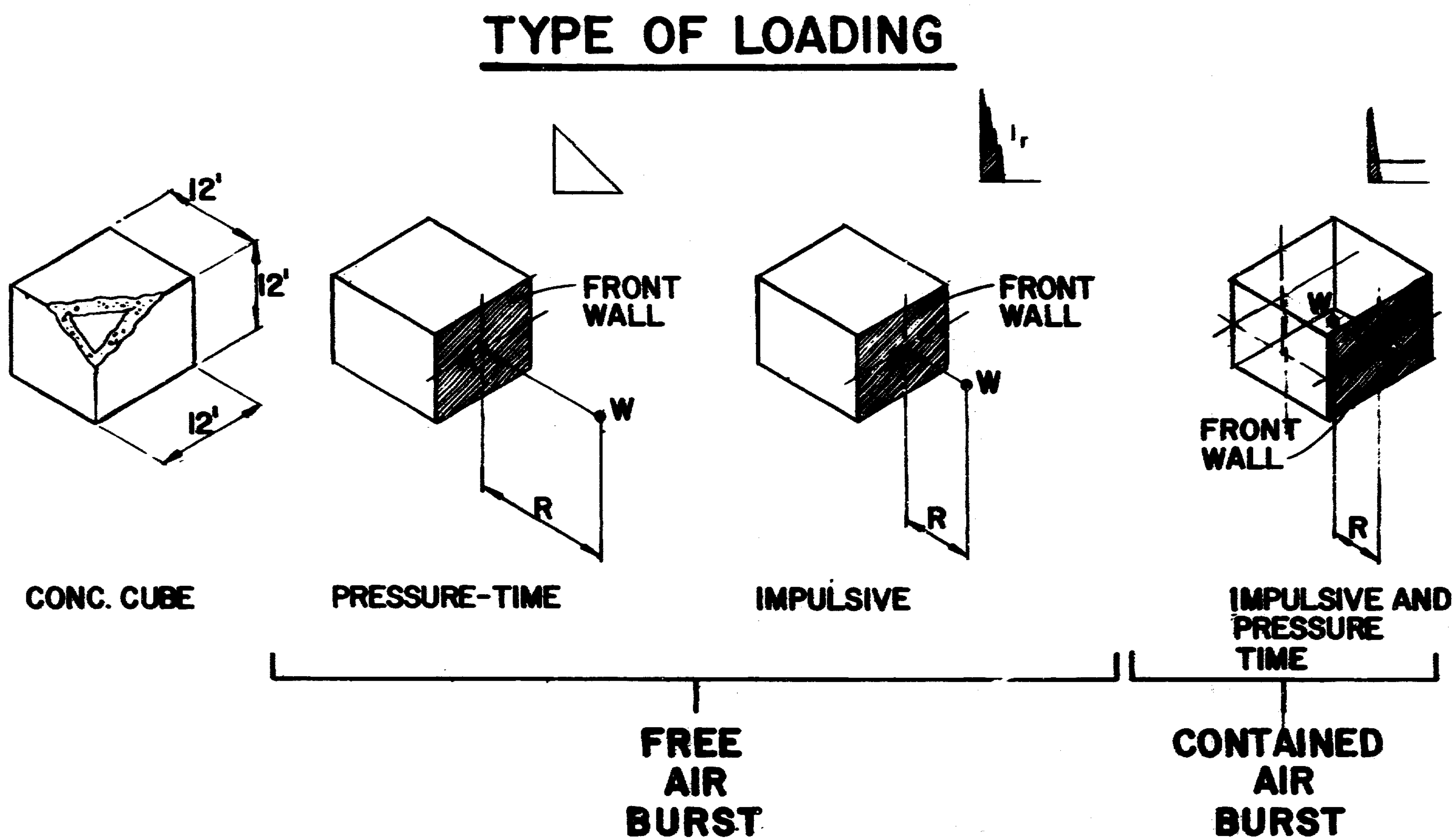

TYPE OF LOADING
12'
12'
12'
FRONT WALL
W
R
I_r
FRONT WALL
W
R
W
FRONT WALL
R
CONC. CUBE
PRESSURE-TIME
IMPULSIVE
IMPULSIVE AND PRESSURE TIME
FREE AIR BURST
CONTAINED AIR BURST

FIG. 2

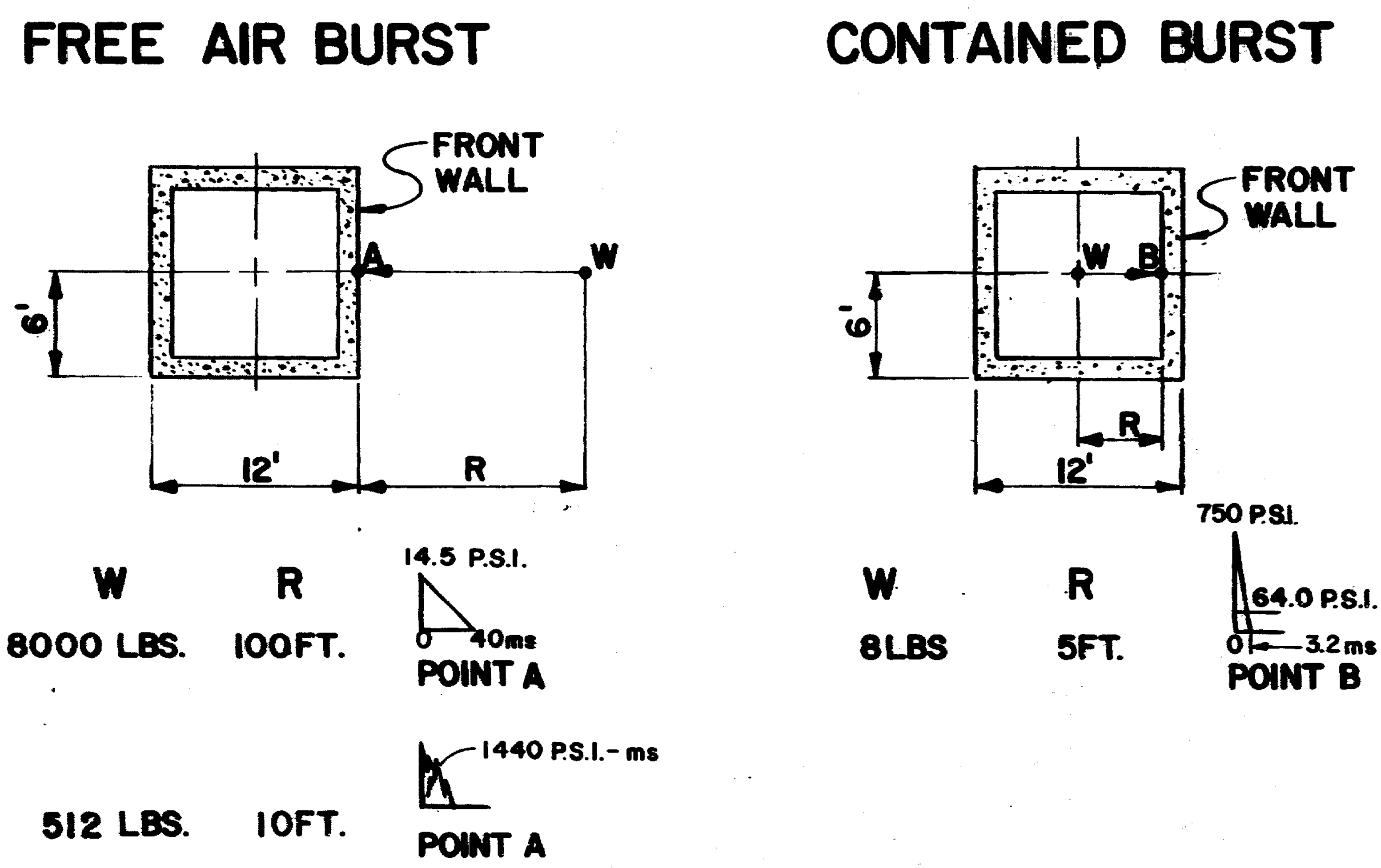
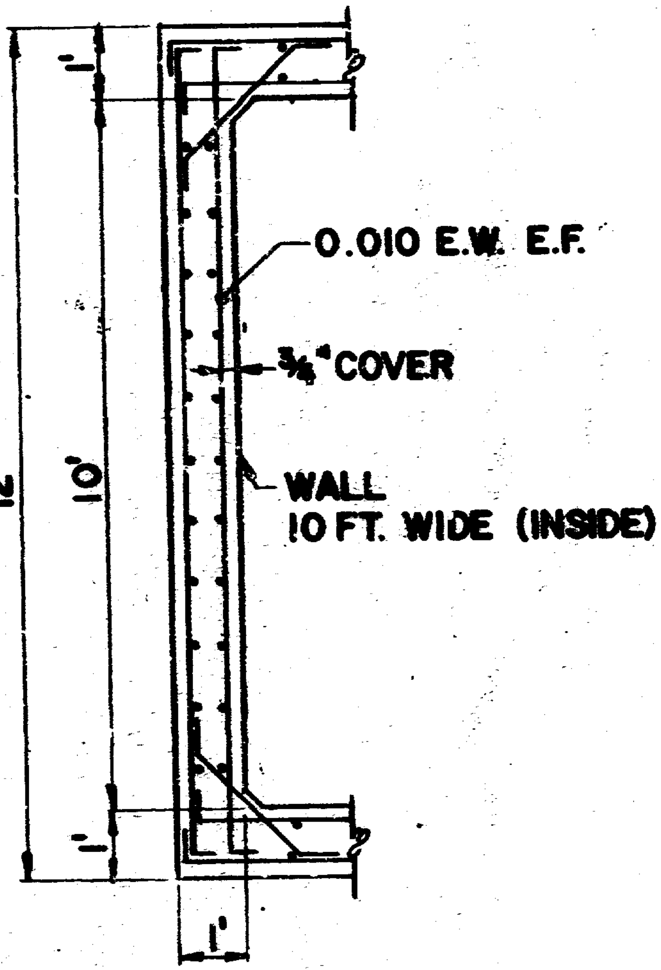

FREE AIR BURST
FRONT WALL
A
W
6'
12'
R
W
R
8000 LBS.
100FT.
14.5 P.S.I.
0
40ms
POINT A
512 LBS.
10FT.
1440 P.S.I.- ms
POINT A
CONTAINED BURST
FRONT WALL
W
B
6'
R
12'
W
R
8LBS
5FT.
750 P.S.I.
64.0 P.S.I.
0
3.2 ms
POINT B

FIG. 3



REINFORCED
CONCRETE WALL
(TWO-WAY SLAB)

FIG. 4

REFERENCES

FIG. 5

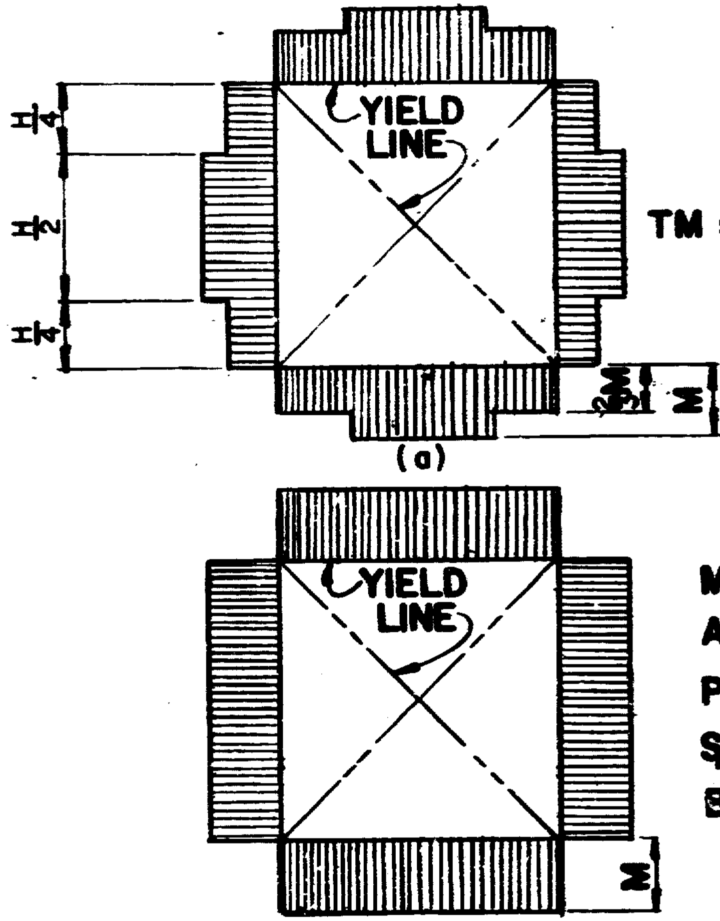
METHOD / PARAMETER	TM5-1300	MANUAL 42	AF MANUAL	PROTECTIVE CONSTR.	S/S HNDBK.	BIGGS
MOMENT OF INERTIA I IN^4/IN	EQ.(5-20)	EQ.(8-10.24)	EQ.(8-22)	FIG.4-6	EQ.(5-8)	PAGE 226
MODULUS OF ELASTICITY E_c $LBS./IN^3$	EQ.(5-17)	EQ.(8-10.23)	EQ.(8-2)	FIG.4-6	EQ.(4-1)	—
STIFFNESS K $LBS./IN^3$	EQ.(5-52)	EQ.(8.-10.33)	TABLE 9-5	TABLE 4-1	TABLE 5.5 FIG. 5.2	TABLE 5.5 FIG. 5.4
PERIOD T ms	EQ.(6-15)	EQ.(8-10.35)	EQ.(9-19)	EQ.(4-26)	EQ.(5-33)	EQ.(5:12)
PLASTIC MOMENT M_p IN.LB./IN.	EQ.(5-1)	EQ.(8-10.12)	EQ.(8-8)	EQ.(3-68)	EQ.(5-7)	PAGE 225
ULT. RESISTANCE r_u P.S.I.	FIG. 5-11 TABLE 5-6	EQ.(8-10.31)	EQ.(8-47)	EQ.(3-70)	TABLE 5.5	TABLE 5.5
ELASTIC DEFLECTION X_E IN.	FIG. 5-17	EQ.(9-1.1)	FIG. 9.6(b)	EQ.(4-28)	EQ.(5-2)	PAGE 231
Xm IN	FIG. 6-7	EQ.(9-3.5)	FIG. 9-11	FIG. 4-13	EQ.(5-47)	FIG. 2.24
Xm IN IMPULSE	EQ.(6-23)	EQ.(9-3.4)	—	EQ.(4-45)	EQ.(5-5.46)	EQ.(5.17)
Xm IN	EQ.(6-23)	—	—	EQ.(4-49)	EQ.(5-54)	—

COMPARISON

FIG. 6

METHOD / PARAMETER	TM5-1300	MANUAL 42	AF MANUAL	PROTECTIVE CONSTR.	S/S HNDBK.	BIGGS
MOMENT OF INERTIA I $IN^4/IN.$	97.0	70.0	80.0	70.0	80.0	80.0
MODULUS OF ELASTICITY E_c $LBS./IN.^3$	4.3×10^6	5.0×10^6	4.3×10^6	5.0×10^6	4.3×10^6	4.3×10^6
STIFFNESS K $LBS./IN.^3$	1015	1370	1000	1370	1000	1000
PERIOD T ms	8	6	8	6	8	8
PLASTIC MOMENT M_p IN.LB./IN.	47,500	44,650	44,650	44,650	47,500	47,500
ULT. RESISTANCE r_u P.S.I.	132	149	149	149	158	158
ELASTIC DEFLECTION X_E IN.	0.13	0.11	0.16	0.11	0.16	0.16
Xm IN	0.16	0.12	0.18	0.13	0.18	0.16
Xm IN IMPULSE	5.7	5.7	—	5.7	4.2	4.2
Xm IN	7.7	—	—	4.2	4.2	—

TWO-WAY SLAB
YIELD LINE DISTRIBUTION OF MOMENTS



TM 5-1300

MANUAL 42
A F MANUAL
PROTECTIVE CONSTR.
S/S HNDBK.
BIGGS

(b)
FIG. 7

FORMULAS FOR MOMENT OF INERTIA

$$I_a = \frac{bT^3}{24} + \frac{b(k'd)^3}{6} + \frac{npbd^3(1-k')^2}{2}$$ TM 5-1300

$$I_a = \frac{bd^3}{2}(5.5p + 0.083)$$ (APPROX.) S/S HNDBK.
BIGGS
A F MANUAL

$$I_a = \frac{bd^3}{24} + \frac{b(k'd)^3}{6} + \frac{npbd^3(1-k')^2}{2}$$ MANUAL 42
PROTECTIVE CONSTR.

FIG. 8

MODULUS OF ELASTICITY

$E_c = W^{1.5} 33 \sqrt{f_c'}$ — TM 5-1300, A F MANUAL, S/S HNDBK., BIGGS

$E_c = 1000 f_c'$ — MANUAL 42, PROTECTIVE CONSTR.

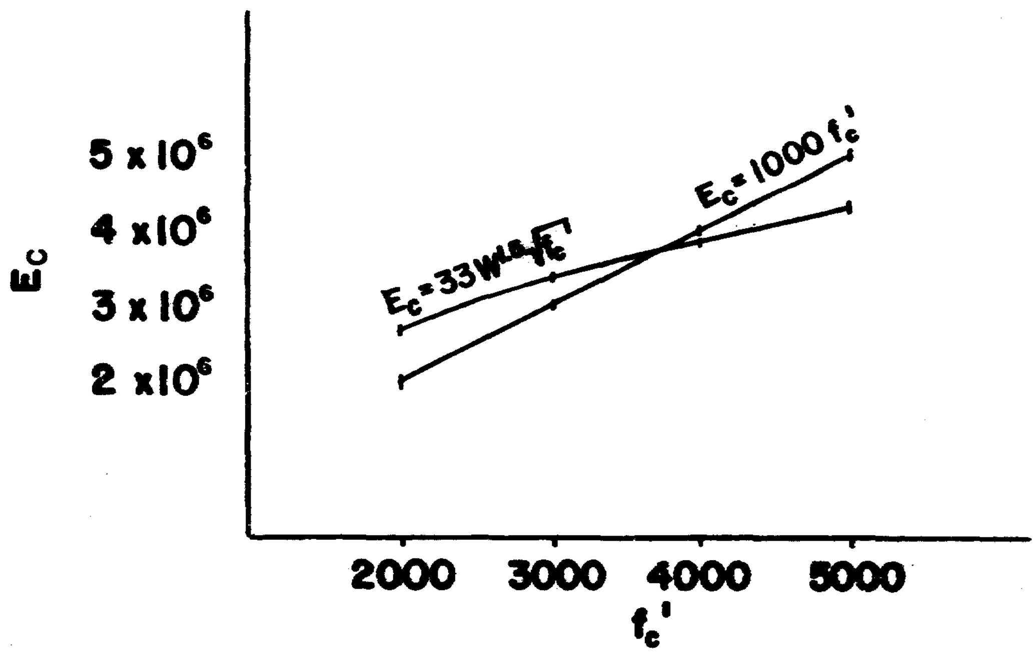
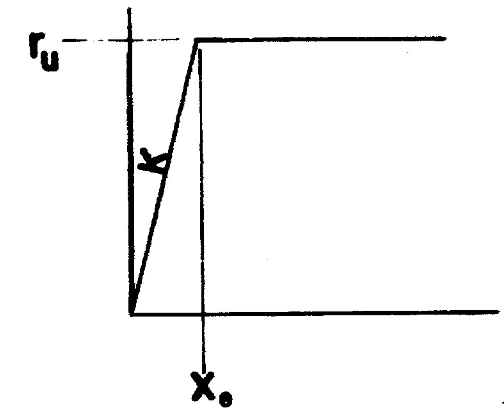


FIG.9

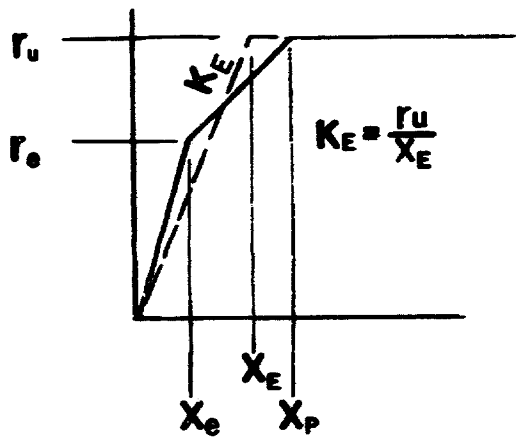
STIFFNESS



MANUAL 42

$K = (307 + \frac{500}{a^3}) \frac{E_c I_a}{L_s^4}$

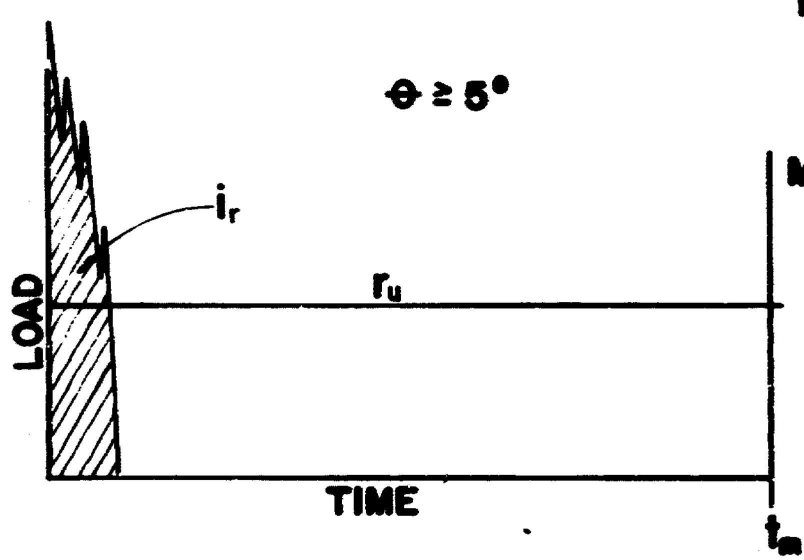
$a = \frac{L_L}{L_s}$



TM5-1300
A F MANUAL
S/S HNDBK.
BIGGS
PROTECTIVE CONSTR.

FIG. 10

LARGE DEFLECTION



TIME FOR MAXIMUM RESPONSE

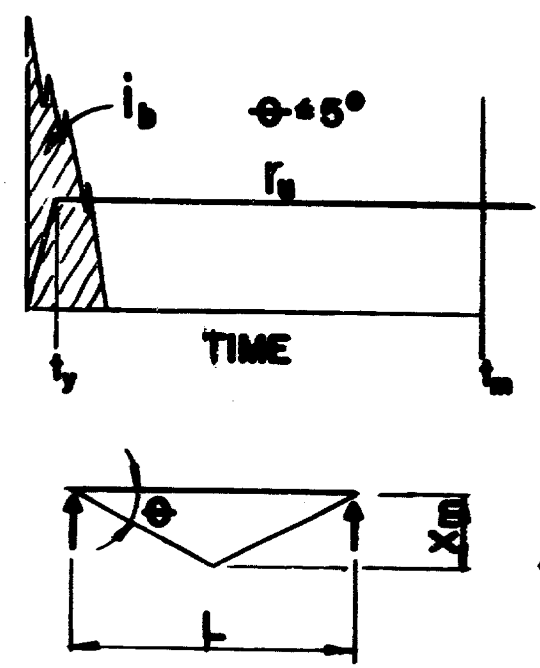
$$t_m = \frac{i_r}{r_u}$$

MAXIMUM DEFLECTION

$$X_m = \frac{i_r^2}{2M_e r_u}$$

FIG. 11

LIMITED DEFLECTION



MAXIMUM DEFLECTION

$$X_m = \frac{M_s}{M_e r_u}\left(\frac{I_b^2}{2M_s} - \frac{r_u X_E}{2} + \frac{M_e r_u X_E}{M_s}\right)$$

$$\tan^{-1}\frac{2X_m}{L} = \theta$$

FIG. 12

A Manual for the Prediction of Blast and Fragment Loadings on Structures

W. E. Baker
J. J. Kulesz
P. S. Westine
P. A. Cox
J. S. Wilbeck

Southwest Research Institute
San Antonio, Texas

ABSTRACT

This paper describes a manual which was prepared to provide Architect-Engineer (AE) firms guidance for the prediction of air blast, ground shock and fragment loadings of structures as a result of accidental explosions in or near these structures.

The primary objective of the project, which was funded by the U. S. Army Corps of Engineers, was to develop a manual which is complementary to existing structural design manuals and can be used (in combination with other manuals) by AE firms to design new buildings which are resistant to blast and fragmentation effects of an accidental explosion. Another objective was to aid in the assessment of the explosion-resistant capabilities of existing buildings at the Pantex Plant near Amarillo, Texas.

The manual is specific for new or existing facilities at the Pantex Plant. However, most data and prediction methods are presented in general terms and can be applied to other high explosive facilities if proper modifying factors are used.

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Mr. Murray Burnette, U. S. Army Engineer Division, Huntsville

Mr. Lawrence M. Paradee, Amarillo Area Office, DOE
Mr. Bob L. Slater, Amarillo Area Office, DOE
Dr. Chester E. Canada, Mason and Hanger-Silas Mason
Mr. A. G. Papp, Mason and Hanger-Silas Mason

Other staff members at SwRI who contributed significantly to the literature search, analysis and technical writing included Mr. Mark G. Whitney, Mr. Gerard J. Friesenhahn, Ms. Patricia K. Moseley, Dr. James L. Rand, Mr. John P. Riegel III, Ms. Deborah J. Stowitts, and Mr. Van B. Parr.

PURPOSE AND OBJECTIVE

The purpose of this manual is to provide Architect-Engineer (AE) firms guidance for the prediction of air blast, ground shock and fragment loadings of structures as a result of accidental explosions in or near these structures.

The primary objective is to develop a manual which is complementary to existing structural design manuals and can be used (in combination with other manuals) by AE firms to design new buildings which are resistant to blast and fragmentation effects of an accidental explosion. Another objective is to aid in the assessment of the explosion-resistant capabilities of existing buildings at the Pantex Plant.

The manual is specific for new or existing facilities at the Pantex Plant. However, most data and prediction methods are presented in general terms and can be applied to other high explosive facilities if proper modifying factors are used.

SCOPE

The topics covered in this manual are:

- General considerations affecting blast, ground shock, and fragment hazards in high-explosive facilities,
- Explosives and damage mechanisms,
- Air blast from accidental explosions resulting in both internal and external blast loading of structures,
- Air blast spalling of concrete walls,
- Air blast hazards to personnel,
- Cratering and ground shock, including effects on buildings, equipment and personnel,

• Fragmentation, including methods for predicting fragment characteristics, trajectories, dispersion and impact effects,

• Hazards to personnel from fragments,

• Explosive initiation by fragments, overpressures, heat, friction, crushing, pinching, etc.,

• Dynamic properties of materials of construction, and

• Overview of dynamic structural analysis and design methods.

Included in appendices are tables of properties of explosives, an extensive bibliography, and an SI metric conversion table.

Methods and procedures included in the manual are intended to be applied by an engineer with a working knowledge of structural dynamics, with the aid of, at most, a desk calculator. Example problems are included for all prediction graphs. Confidence levels for prediction methods are cited throughout and needs for design verification by proof tests or experimental research are identified where appropriate.

General theory or fundamental principles are given for each topic if needed, and advanced concepts and theories identified, but not rigorously treated in the manual.

The complementary nature of this manual requires its use in conjunction with other references (1-20), rather than as a single comprehensive manual, if one wishes to cover all aspects of loading from accidental explosions, response to and damage from such explosions, and design for resistance to or survival under accidental explosions. Related items which are not covered in depth in this manual, but are well treated in other general references, are the following:

• Basic physics of air blast,

• Detailed analysis methods for elastic-plastic dynamics of structures,

• Fundamental studies of cratering and ground shock,

• Exterior and terminal ballistics of fragments and accident missiles over wide ranges of missile and target properties,

• Fundamentals of dynamic properties of materials, and

• Detonation physics.

CONTENTS

This manual is organized into eight chapters and supporting appendices. The first chapter serves as a brief introduction, and contains no technical details, but all following chapters are technically oriented.

Chapter 2 covers general considerations in explosive safety and design at the Pantex Plant. It covers the scope of explosive safety in a general way, describes general procedures for designing or evaluating buildings subjected to high explosive hazards, gives typical building configurations, and discusses impact of safety regulations and procedures on explosion-resistant design. The applicability and limits of applicability of the manual are noted.

Chapter 3 gives qualitative discussions of the predominant aspects of explosive hazards and damage mechanisms associated with accidental explosions. The effects are also limited to those which could conceivably occur from accidental explosion of HE or chemicals used in processing of HE at Pantex. This chapter serves as a preview of Chapters 4, 5 and 6.

Chapter 4 gives relatively detailed coverage of air blast from those classes of accidental explosions which could conceivably occur in the Pantex Plant. Topics covered include blast waves from single and multiple sources, effects of containment and venting, methods of predicting blast loads on structures for both internal and external explosions, air blast spalling of concrete walls, and air blast hazards to personnel.

Cratering and ground shock are covered in Chapter 5. Basic phenomena are discussed, and methods are given for prediction of explosive cratering, ground shock waves, and effects of ground motion on buildings, equipment and personnel.

Chapter 6 covers fragmentation and its effects for explosions which could occur at Pantex. General phenomena are discussed, followed by methods for predicting fragment characteristics, flight, and impact effects.

Chapters 4, 5 and 6 are the longest and most detailed chapters in the manual, but they are supported by two relatively short chapters giving additional information. Chapter 7 gives data on dynamic properties of materials of construction which are or could be used in explosives facilities at the Pantex Plant while Chapter 8 gives an overview of design methods for structures typical at Pantex.

In each chapter giving prediction methods, one or more example problems for each method are included following the appropriate sections. Each chapter also contains a list of symbols and a list of all references cited in the chapter.

Ancillary material included in the manual are appendices giving a set of unit conversion tables to and from SI metric units, explosive properties, and an extensive bibliography.

DISCUSSION

This manual contains considerable material which is new, and not available in other manuals or references. We now illustrate some of these features.

There are fits to relatively recent data for wall loading from blast waves at small scaled standoff distances. Figures 1 and 2 show these fits. They allow better predictions in this strong shock regime of details of wall loading than do methods presented in Reference 7.

Recently declassified data on the effects of various brittle casing materials for explosives on air blast (Refs. 21 and 22) are used as a basis for prediction of casing effects. These results are quite at variance with previous prediction equations which showed reduction in blast overpressure and impulse. In many instances, the brittle casings enhanced blast, compared to bare explosive charges with the same weight of explosive. Figures 3 and 4 show that the casing weight can be added to the charge weight to obtain a new effective charge weight, and blast overpressure and impulse predicted with reasonable accuracy for brittle casing materials.

Other novel features in Chapter 4 are inclusion of prediction curves for effect on blast waves of cylindrical charge shape, multiple simultaneous detonations, and multiple sequential detonations. New prediction curves are also included for vented gas pressure parameters for internal explosions accounting for mass of blowout vent covers. Figure 5 shows one set of scaled curves generated by a special computer program developed for this purpose.

None of the complementary references contain any appreciable information for prediction of cratering and ground shock effects of accidental explosions. Chapter 5 covers this topic, and gives prediction methods for crater dimensions (Figure 6), ground motions outside the crater (Figures 7 and 8), and effects of ground motions on buildings, equipment and personnel. Predictions of response of buried structural walls and pipes are also included in this chapter.

Fragmentation and fragment impact effects are covered in only a few other design manuals, including References 5, 7, 11 and 12. The coverage in Chapter 6 is much more extensive. Unique features are inclusion of methods for prediction of building fragmentation for internal explosions, a scaled curve for prediction of maximum fragment range (Figure 9), and scaled curves for prediction of initiation of cased and bare explosives by fragment impact (Figures 10 and 11).

Chapter 7 emphasizes the information available on dynamic properties of materials most common in construction of explosion-resistant structures at Pantex and elsewhere. The materials include the structural metals steel and aluminum, concrete and woods. Little data were found on frangible materials used in construction of blowout panels.

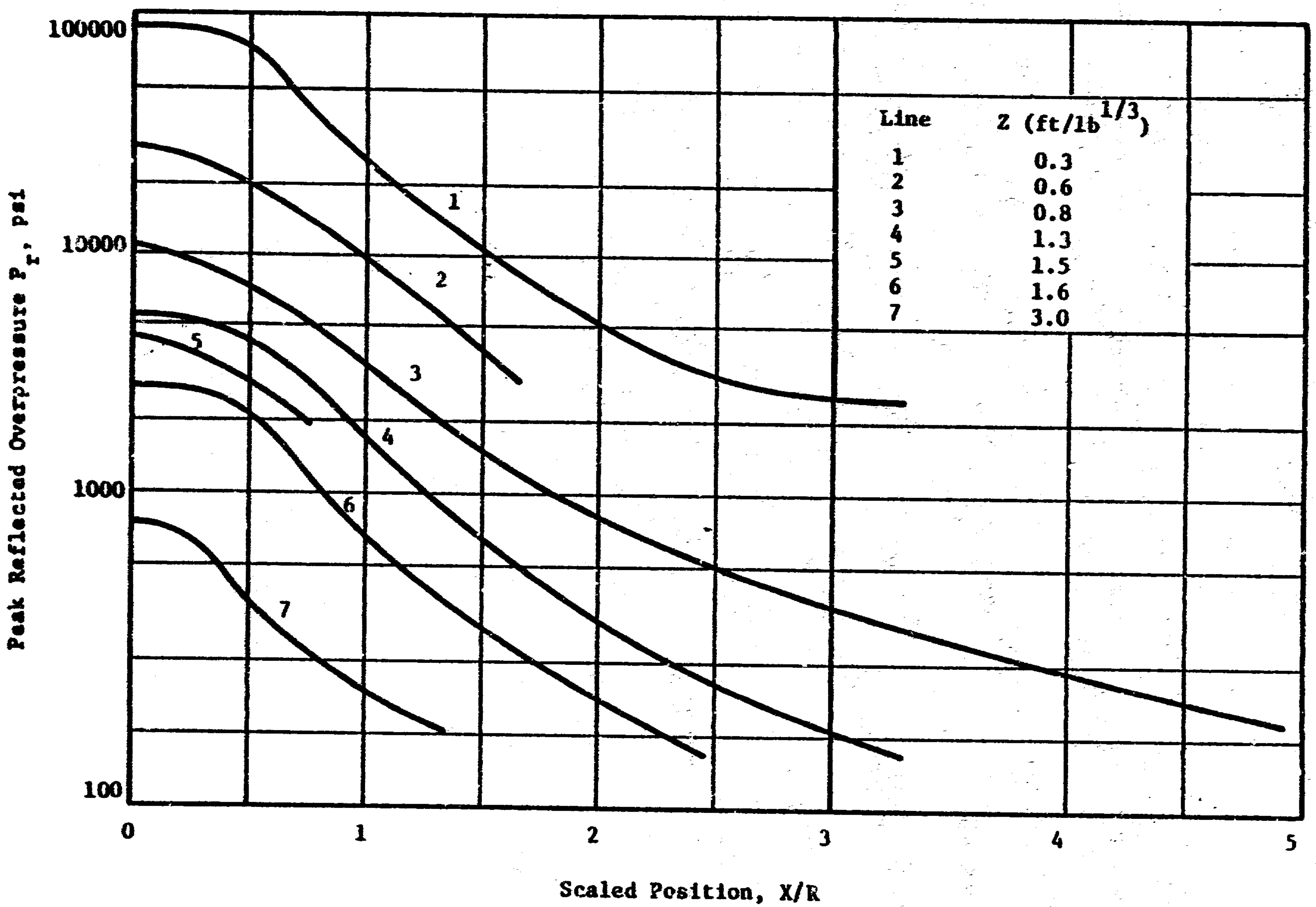

Figure 1 Peak Overpressure versus Scaled Position for Different Scaled Distances for Single Charge

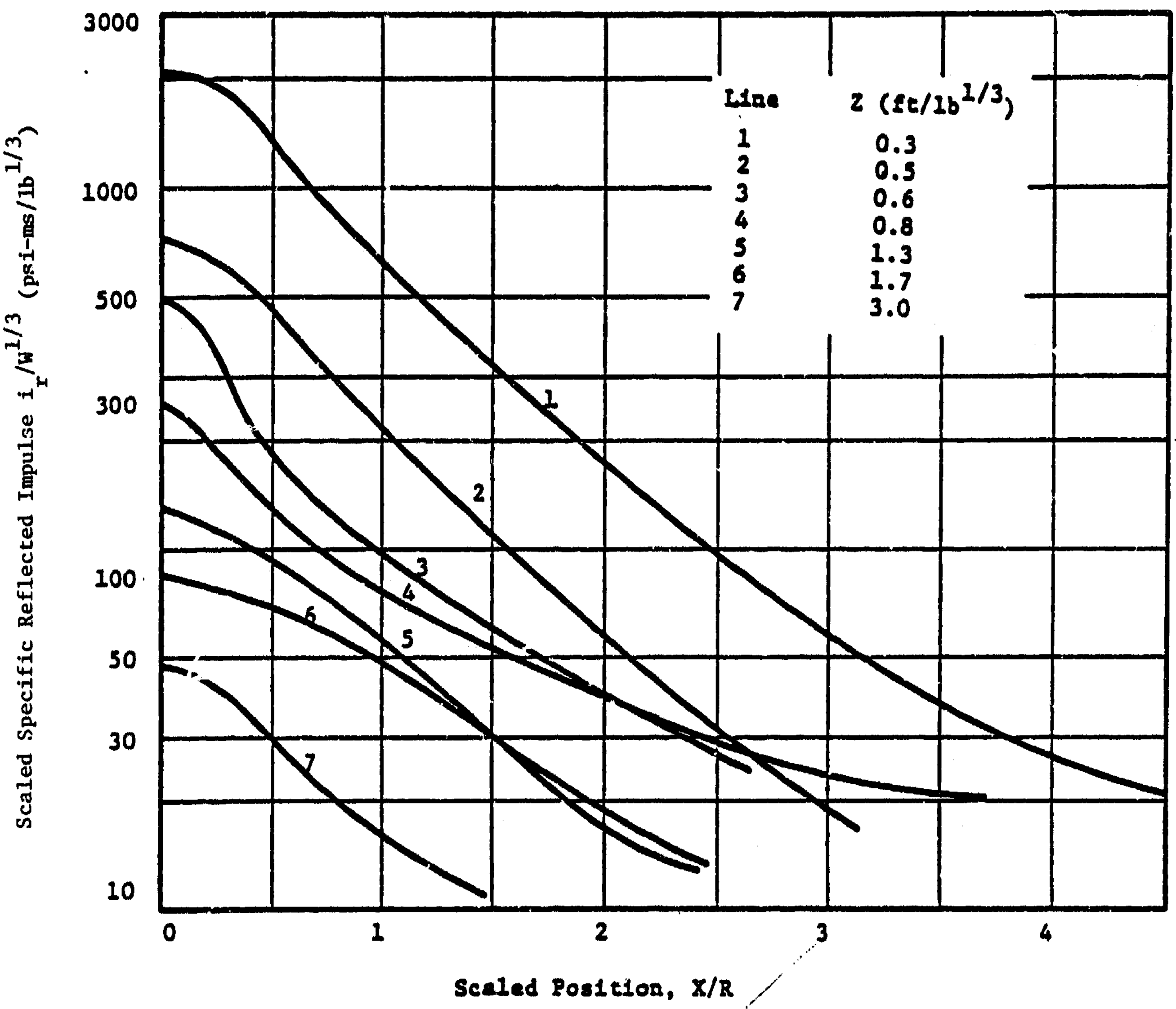

Figure 2 Scaled Specific Impulse versus Scaled Position For Different Scaled Distances for Single Charge

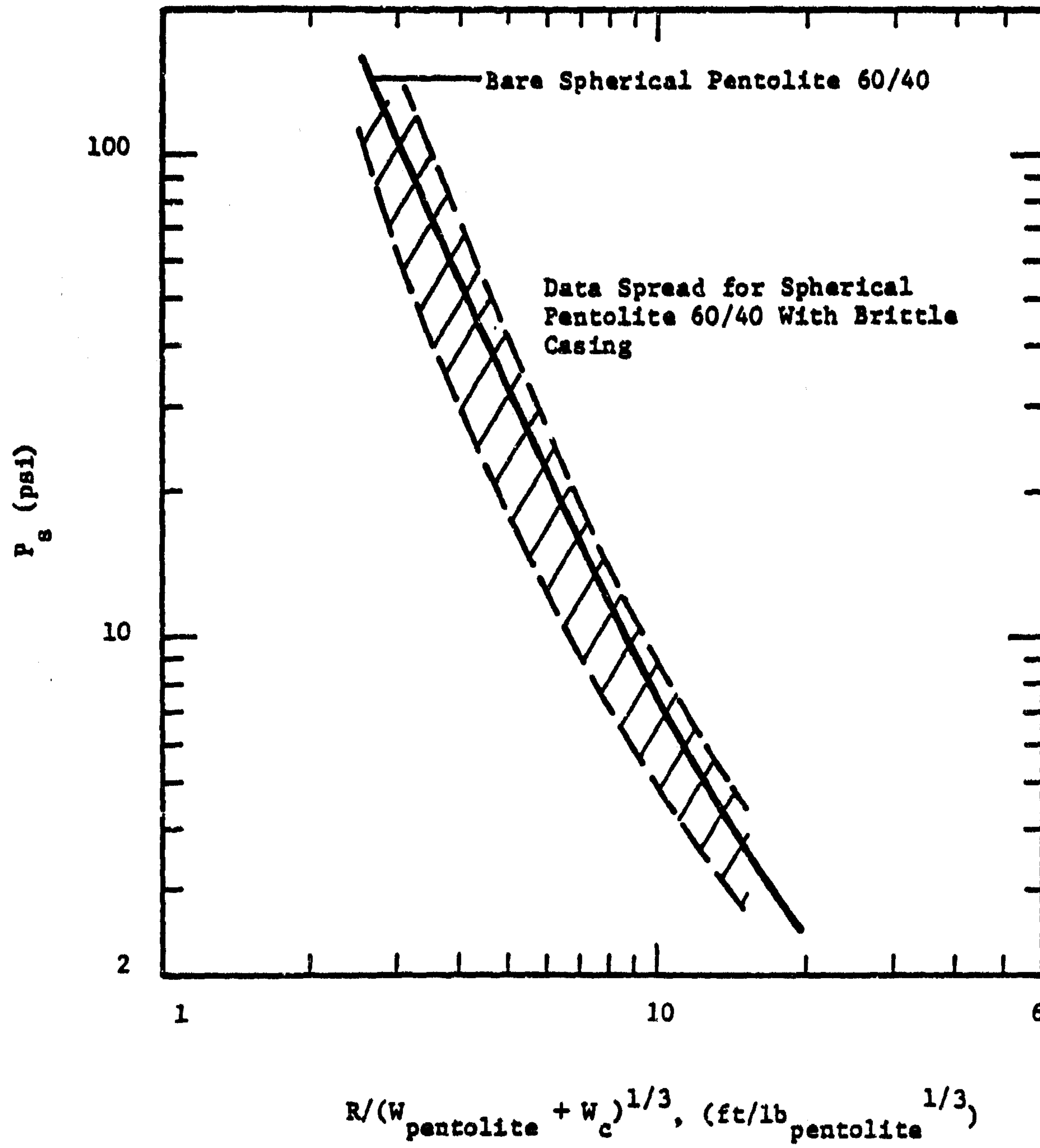

Figure 3 Peak Side-On Overpressure for Spherical Pentolite 60/40 Light, Brittle Case

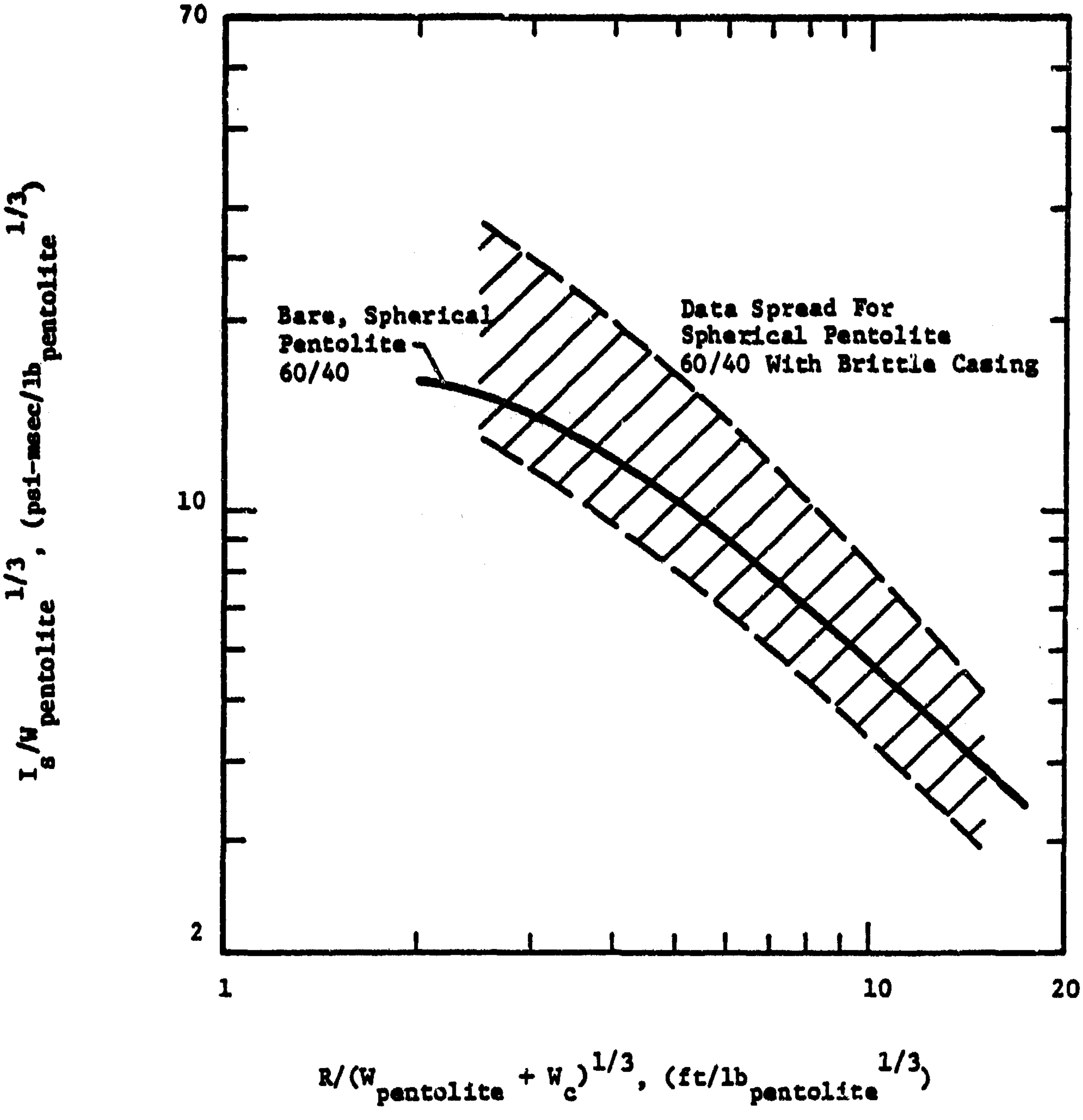

Figure 4 Scaled Side-On Impulse for Spherical Pentolite 60/40 With Light, Brittle Case

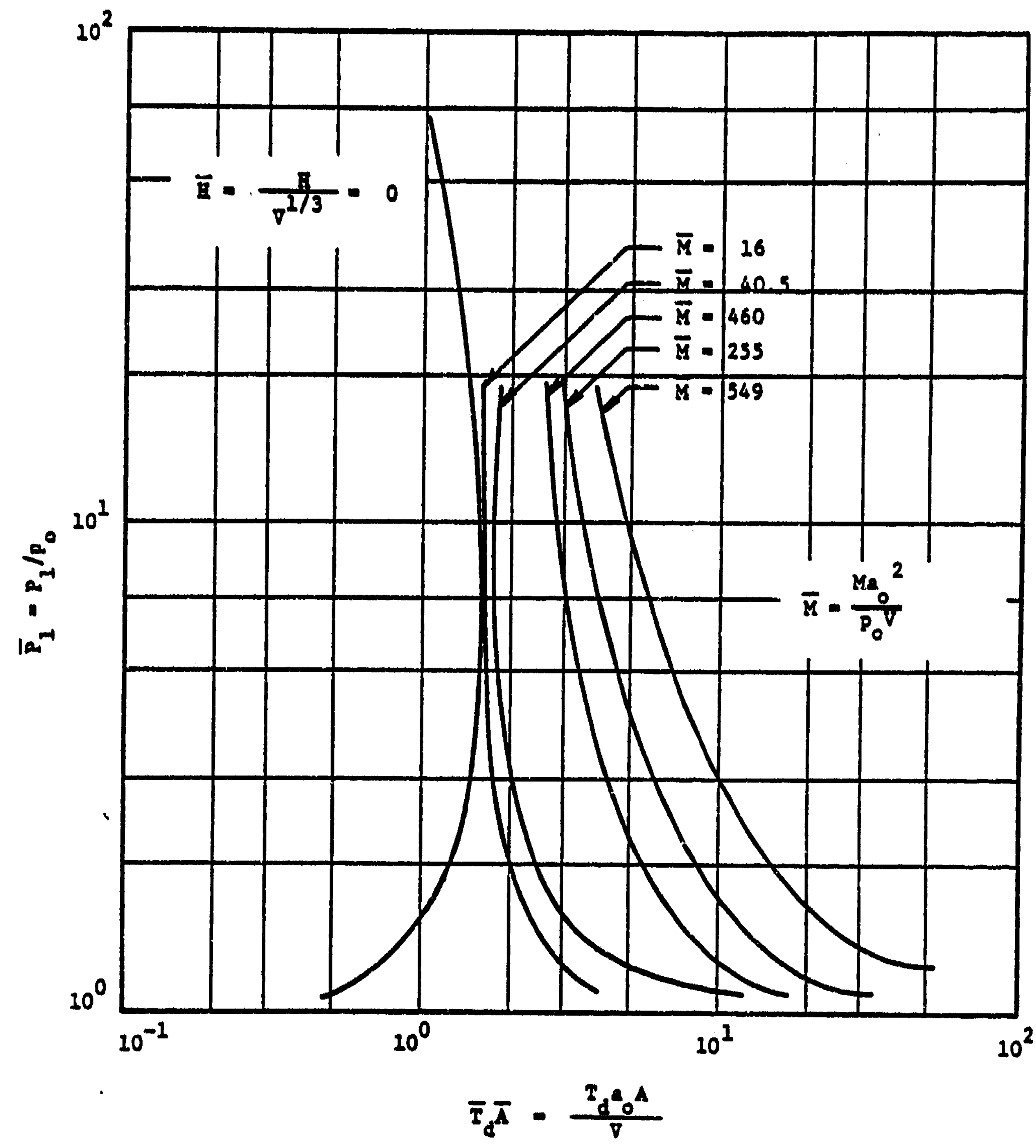

Figure 5 Plot of Scaled Pressure versus Scaled Duration, Various Scaled Masses of Vent Covers ($\bar{M}$), for $\bar{H} = 0$

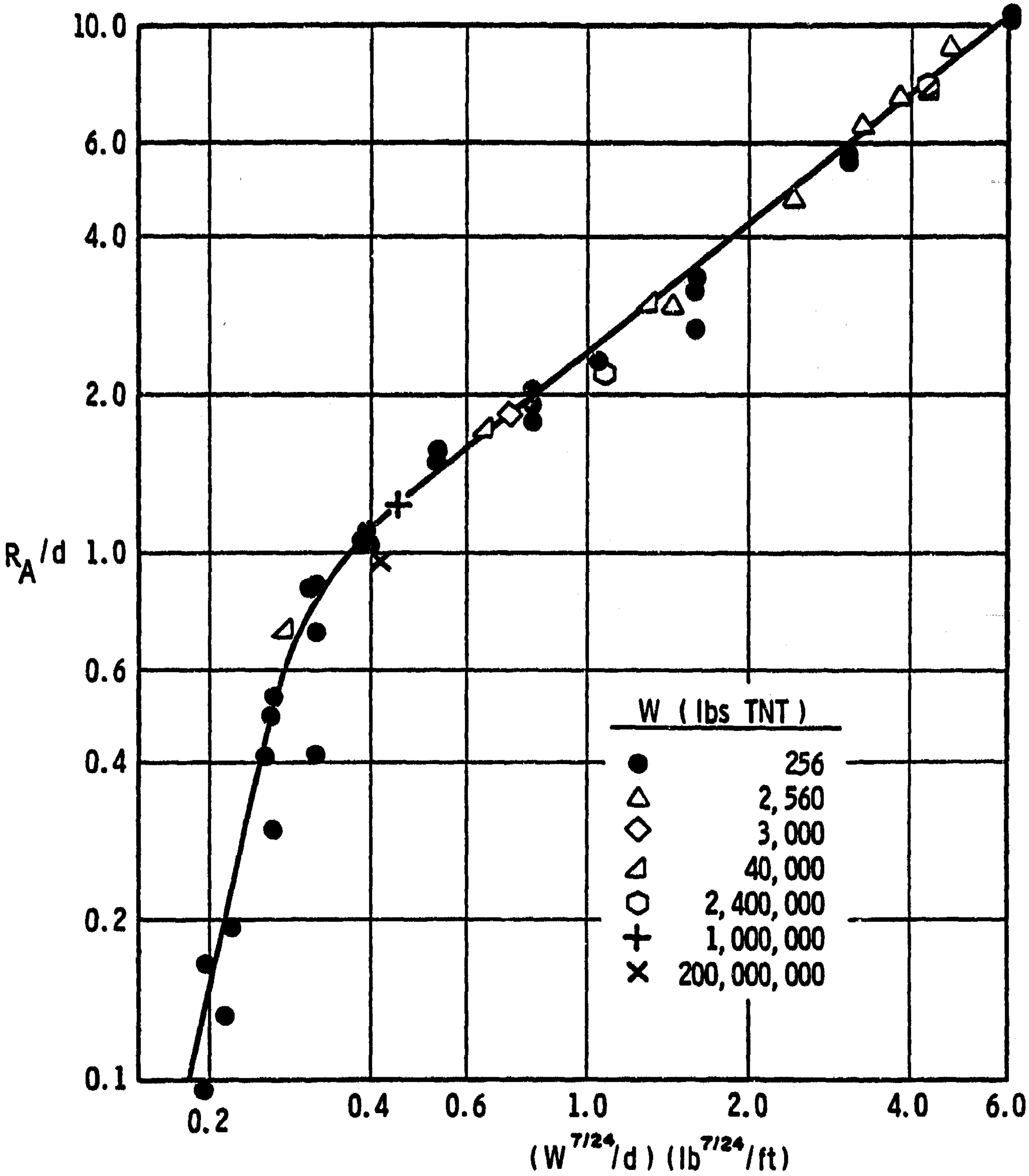

Figure 6 Apparent Crater Radius R_A/d versus $W^{7/24}/d$ in Alluvium

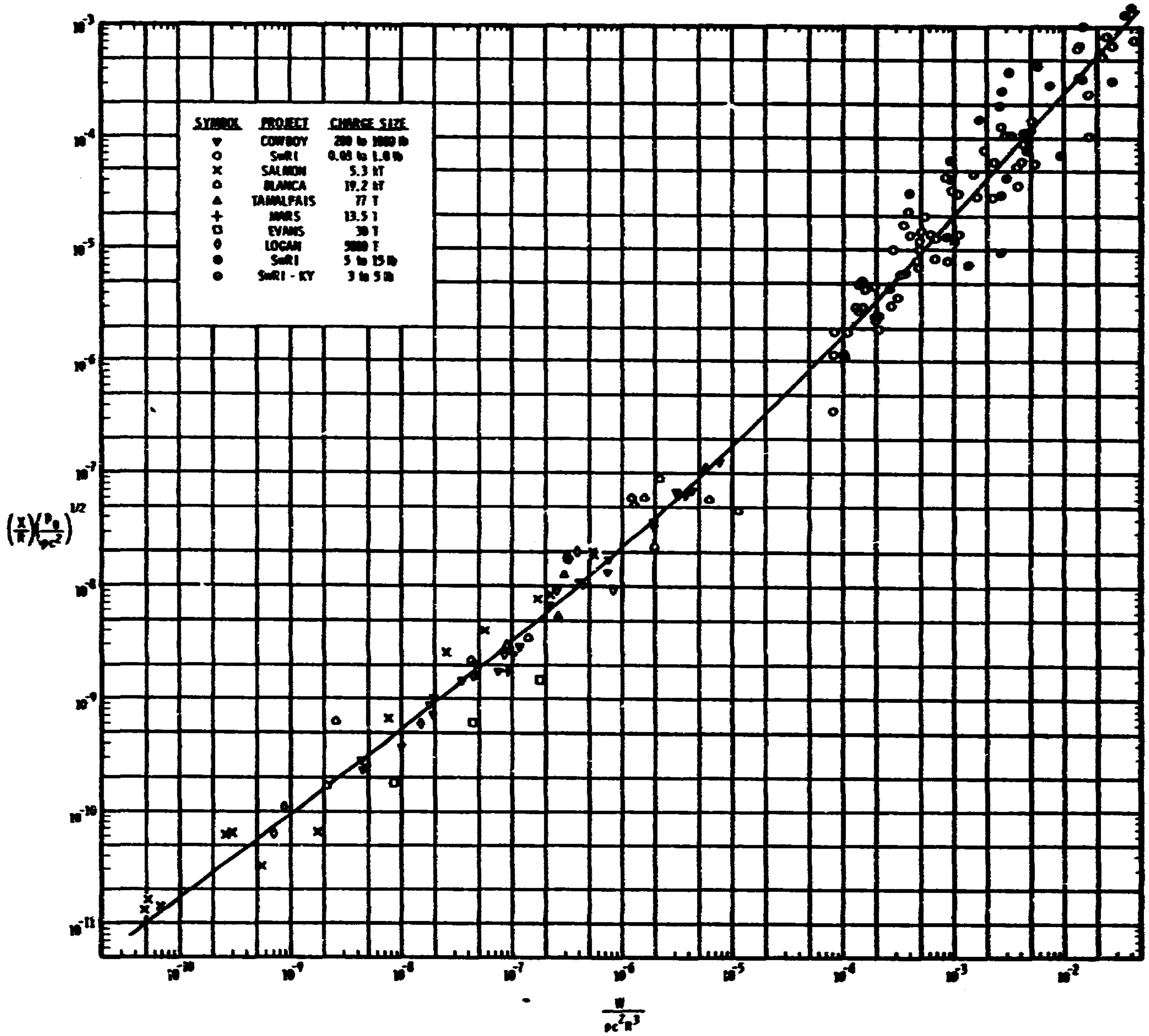

Figure 7 Radial Maximum Displacement in Rock and Soil

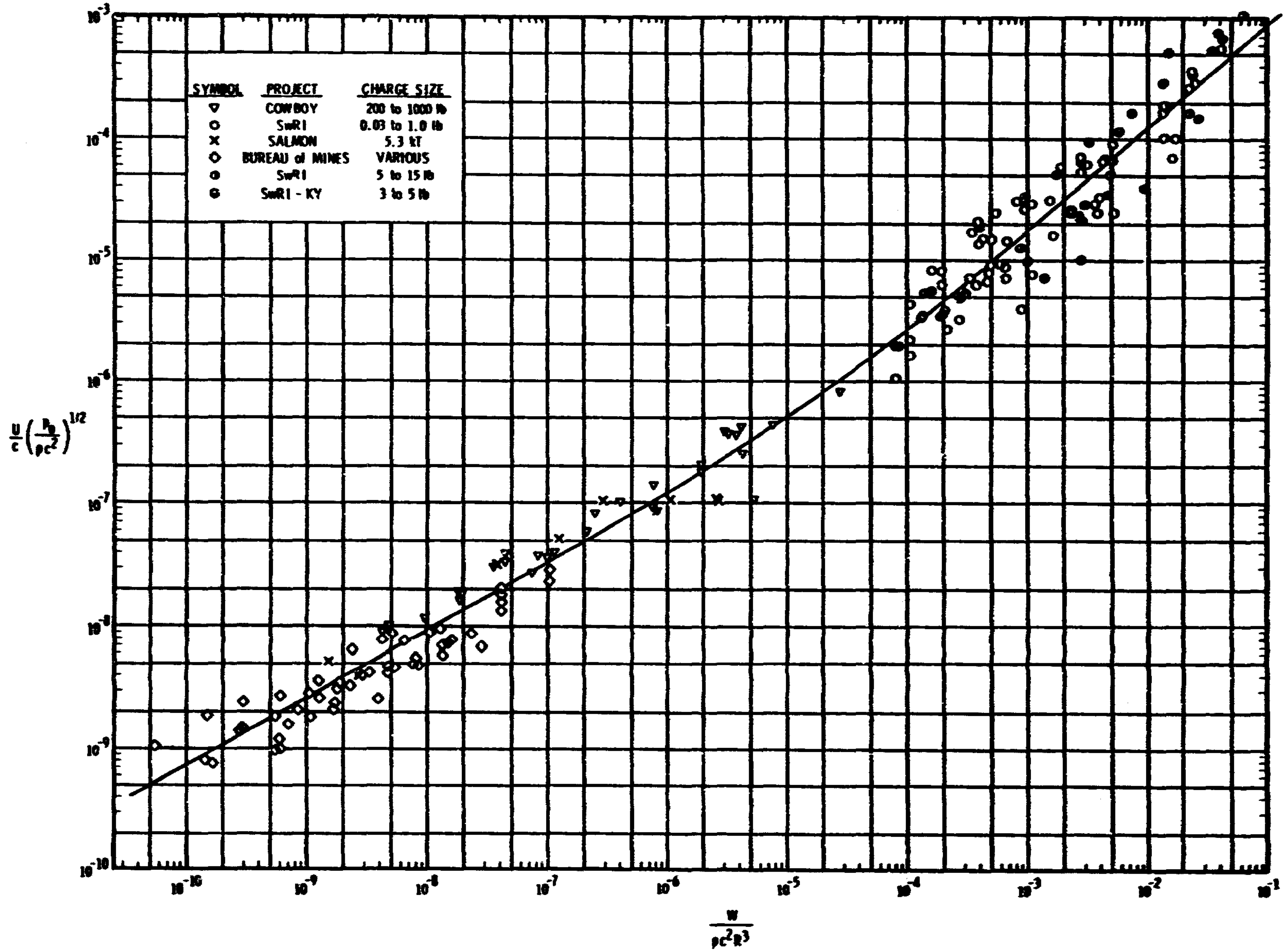

Figure 8 Radial Particle Velocity in Rock and Soil

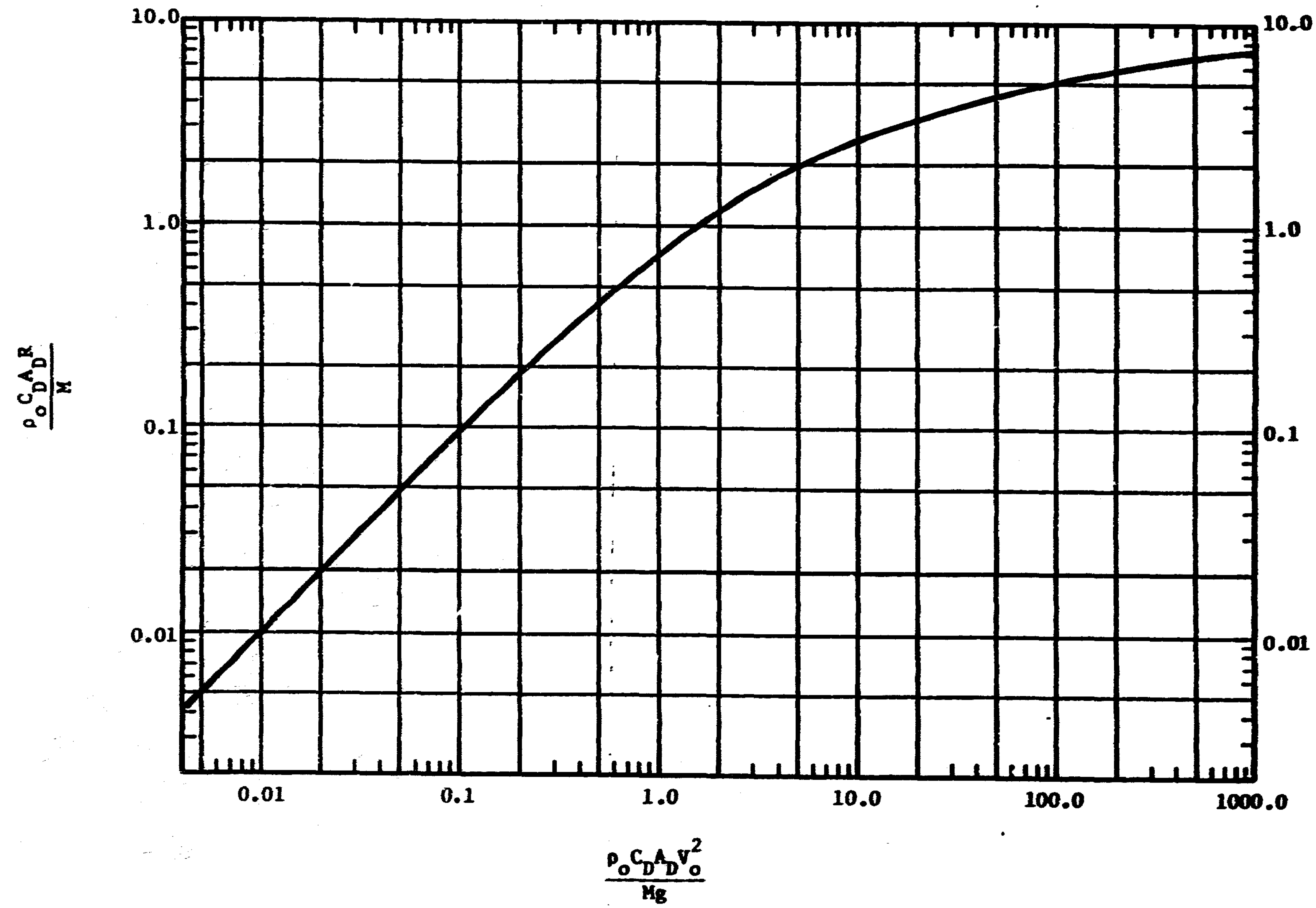

Figure 9 Scaled Curves for Fragment Range Prediction (Drag Fragments)

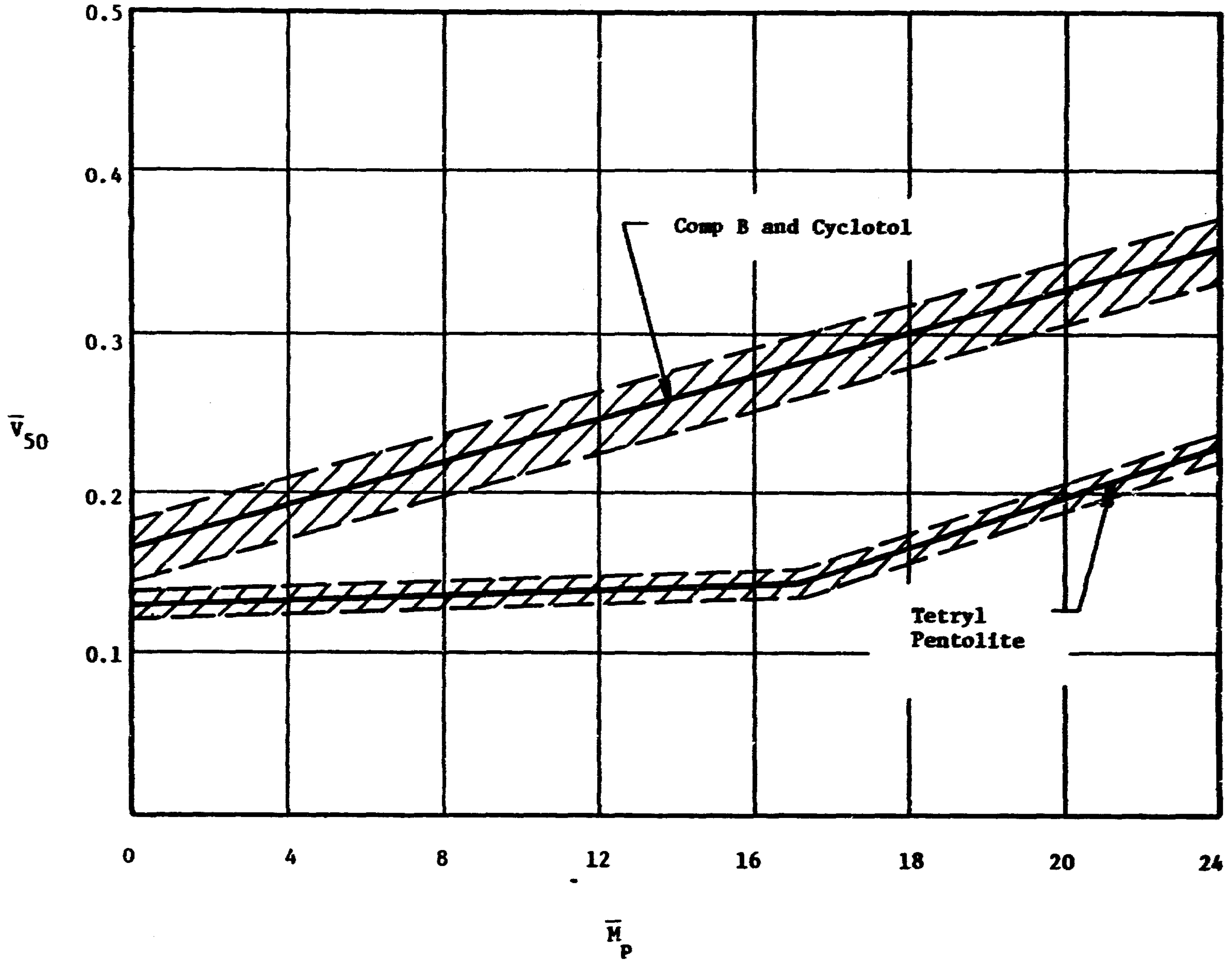

Figure 10 $\overline{V}_{50}$ versus $\overline{M}_p$ for Bare Explosives Including 1σ Error Bands

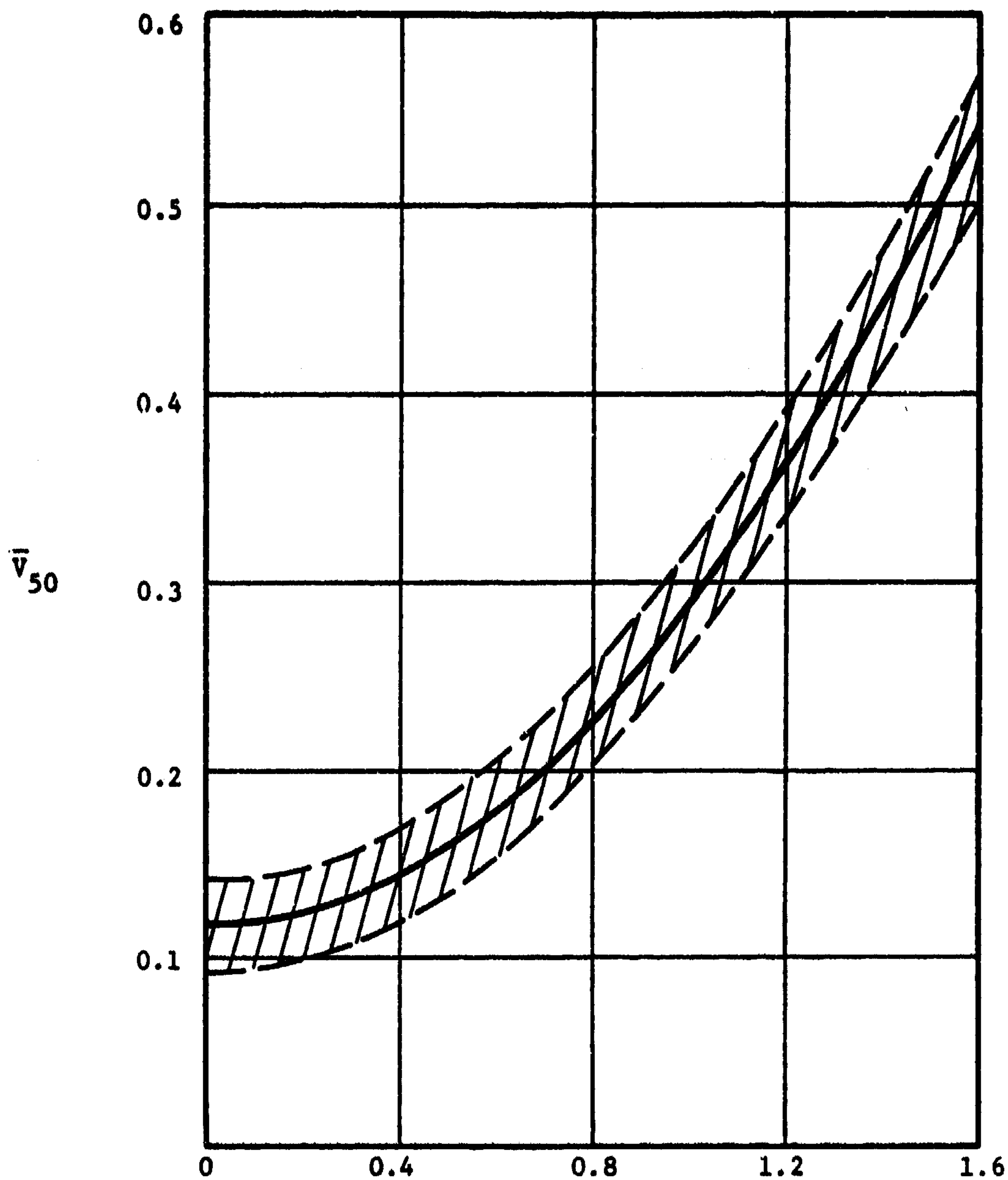

Figure 11 $\bar{V}_{50}$ versus $\bar{h}$, Heavy Explosive Confinement Including 1σ Error Bands

Details of structural dynamic design methods are readily available in complementary references (Refs. 3, 4, 5, 6, 7, 8 and 20), and so, are not included in this manual. But, Chapter 8 includes a review of these methods and a flow chart to aid an AE firm in proper choice of dynamic design methods.

The authors feel that this manual should be a valuable reference text for engineers involved in design of structures to resist high explosive detonations, or in assessment of effects on existing structures. Throughout, need for further work to improve prediction methods has also been highlighted.

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TECHNOLOGY BASE OF THE NAVY EXPLOSIVES SAFETY IMPROVEMENT PROGRAM

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ABSTRACT

NESIP offers an organized set of novel methods, codes and formulae to

- o solve any explosion safety problem -- as best one can with data at hand
- o to explain and correlate existing data -- among many specialized fields
- o predict new weapons effects and scenarios -- as needs may arise.

These methods were applied and tested over a broad spectrum of Navy weapons that includes torpedoes, missiles, bombs and shells - in many different scenarios. Navy directives now require that all new weapons be analyzed by these techniques during their development stage for all forseeable scenarios of the weapon lifetime.

All current NAVY weapons analyzed and tested so far were found either acceptable hazards near 500 feet without change or could readily be made so by

- o minimal shields -- against blast and fragments, or
- o minimal inhibitors -- against sympathetic detonation and burning, or
- o prudent variations in stacking and storage, or
- o minimal barricades by exploiting natural terrain and cover.

PREFACE

The author apologizes to the reader if the text is too terse to be clear.
A main idea is a sobering reminder to myself, (hence my apologies to you):
If one cannot say it in one sentence, chances are he has not thought it through.

Yet, the outline of this paper, Table 1, lists nearly 60 novel ideas or approaches,
most of which could appropriately be written as separate papers.
They represent thirty years (I had) of unparalleled opportunities for pio(engi)neering.
The intent here is to provide a reference, a framework for bookkeeping the ideas,
to show how they fit together, not a separate exposition for each separate method.
One can argue, with much justification, that separate papers should have been written.
I agree. But that would mean sixty or so separate books and papers
-- some are book-size now: LA 1664, LA 1665, ARF D125, NOLTR 72-209, NOLTR 79-359.
The blunt fact is that neither of us will live that long. Who would want to!

Abraham Lincoln once wrote:
"Pardon me for writing a long letter. I did not have time to write a short one."
Well, I did take time to write the short one, the Abstract; a longer one, Table 1;
a still longer one, this paper. I did not have time to write all the long ones yet.
When they are written, a reader will first need a guide to "where is it?"
This paper is the guide.

Note also the style: a single sentence or main idea to a line: outline style.
That is because this is a reference, a format to organize ideas, not an exposition.
Of course, to show that a problem exists, that an answer exists, and to write it.
probably accomplishes about 90% of the usefulness that can be offered.
Just as one spoils a joke by explaining it, so it muddles a good idea to belabor it.
I believe, once you understand the idea, you will prefer the succinct format.
Read the paper by following Table 1, topic by topic.
If you want help, call me at (202)394-1166 or (703)533-7973. It is that easy nowadays.

TECHNOLOGY BASE OF THE NAVY EXPLOSIVES SAFETY IMPROVEMENT PROGRAM (NESIP)

GOALS AND APPROACH

NESIP was founded by CNO OP41 and is directed by the NAVSEA Safety Office 04H3. The main concern is the hazards from loading at pierside and in storage[1], but the technology usually applies to parallel Navy programs on ship vulnerability. Land-based scenarios fall within the purview of the DoD Explosives Safety Board, and accordingly, our main guidelines are the DDESB "acceptable hazard" criteria:

Blast: no more than 1 psi

Fragments: fewer than 1 fragment/600 ft^2 with 58 ft-lbs energy or more.

Our first goal is to appraise the blast and fragment hazard comprehensively, and when necessary to invent means to reduce the hazard arc to feasible limits. A hazard arc of 500 feet often has proved a feasible goal for two basic reasons:

1. The Navy limits the loads during handling operations to 1500 lbs or less explosive weight, and 1 psi blast occurs near 500 feet for such a net explosive weight (NEW).
2. Many piers, being 500 feet long, place the hazard arc just off-shore.

NESIP studies the whole spectrum of Navy weapons during handling and storage, and by a recent directive[2] will appraise all future weapons during development for all scenarios during their forseeable lifetime.

Such a scope requires a broader approach than specialized science usually affords. Safety itself demands we do the best we can with what we know now.
The NESIP technology base promises just such a tool for safety problems because they typically involve sparse data, a wide variety of interacting phenomena, ill-defined scenarios, and a host of unforseen and imponderable variables.
For <u>safety problems</u>, more than precision, we need reliable, <u>safe solutions</u>
-- to insure that all the controlling variables have been identified and "bookkeeped".
We do not need rigor so much as we need simplicity
-- to keep solutions workable and to avoid exact solutions to the wrong problems.
We need a comprehensive approach, using all we do know now, to solve the problem now
-- without waiting decades for each specialized field to catch up with the problem.
We need a yardstick of theory, albeit rough,
-- so that when Nature screams some anomaly at us in an experiment,
-- we recognize it and make a better theory next time.
These are all compelling reasons as we see it for using a "unidynamics" approach to safety problems.[3,4]

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TABLE 1. GUIDE TO NESIP TECHNOLOGY BASE

Topical Outline:	Significance	Key equation, code or reference	Key application or prototype: Torpedos			Missiles				Projectiles			Bombs		Scenarios					Overviews		
			Mk 16	Mk 46	Mk 48	TOMAHAWK, HARPOON	2.75" rocket	PENGUIN	HARM, SPARROW	5"/54 HC, all explsvs,	5"/54 HIFRAG, GM	76 mm fixed round	Mk 80 series	Mk 82 in pallets	SSN sub, CG(Belknap)	Machrihanish Magazine	AD/AS workshop	FFG magazines	Pier to AD/AS	White Oak Lab	Ship to shore	IHE concepts
		Codes: 6 term alphanumeric																				
	↓	Refs: NOL=Naval Ordnance Lab																				
		LA = Los Alamos Scient Lab																				
		DDESB= DoD Exp Safety Board																				
	Invention	IDA= Inst for Def Analyses																				
UNIFIED DYNAMICS	Approach to	Exploit:																				
Safety vs sparse information	incomplete	The behavior common to everything																				
Controlling variables	data	$s^2_{tot} = \sum s_i^2 = s_1^2 + s_2^2 +$ as needed																				
GENSHY hypothesis	problem	Basic assumptions: UOIEA																				
MORES principle	↓	Maximize order by maximum dP/dt																				
Action criterion	UNI	$\int(E - E_{thresh})dT = H_{min}$																				
BLAST	Loading in	NOLTR 72-209, LA 1664																				
Unified Theory of Explosions	free air	Y = W+K = E-E$_o$-Q)	o	o												o						
Prompt available energy	↓	$W = \int^{P_o} FdV$, fastest path								o												o
Direct Evaluation of Blast		DEB506					o															
Direct SCaling of data		DSC506					o							o			o					
DaMaGe variable predictions		UTEDMG, 16th DDESB Saf Sem	o	o	o					o					o	o				o		
FORM Factor Method		UTEFORM $B = (1/3)(W/(1 + U))^2$																				o
Non-spherical explosions	↓	Generalized radius of curvature					o															
Non-ideal explosions	UTE	mass effect, waste heat,														o						
Initial vs delayed yield		afterburning, 30 other effects													o							
SURFACE EFFECTS & INTERACTIONS	Burst	LA 1665, LA 1529, IDA P330																				
5 Reflection modes (regular,etc	geometry	$P_{ref} = f(P_i, A)$ $\ln P_r$					o															
Simplified height-of-burst																						
Jetting		$U^2(2) \cong 2U^2(1)$; $N(n) \cong nN(1)$	o												o							
Venting	↓	dW/dT = PU area	o												o	o						
Energy transfer vs	Surf eff.	DU^2 = constant for surrounds	o													o						
momentum transfer	theory	DU= constant w/ venting	o																			
Confinement & berms	w/UTE	Venting sector: (1-cosA)/(1,2)													o	o				o		
Underwater/ground air blast		Partition: $(1,2)/(1+ hM/h_oM_o)$													o							
MATERIAL RESPONSE	Target																					
Acoustic approximations	yields	$W = (P - P_o)/D_oC_o^2 = U/C_o = D/D_o - 1$ etc														o						
Equation of state		$W = ((V_o/V)^k - 1)/k$																				
Law of partial volumes		$V_{total} = \sum V_i$, not $P_{total} = \sum P_i$													o							
Stress-rapid strain	↓	$E-E_o = W+K+Q$, not stress x strain													o							
Waste heat, ideal absorbers	Blast	$Q(P, V) \cong (E-E_o)/2$	o												o							
Ductility vs elongation	shield	max $\Delta L/L \sim L^{-1/2}$													o							
Energy of fracture		E_{fract} = new area $(P\Delta L)_{fract}$													o							

MATERIAL BREAKUP	Target fails							
Statistical model		$dN \sim NdL$ dL = new volume/new area				o		
Average distribution		$N(>L) = N_o \exp(-L/\bar{L})$				o		
Mean frag size & case thick.		$\bar{L}$ = const $X^{1/2}G/P \cong \frac{1}{2}X^{1/2}$(cm steel)				o		
Double slope		$\bar{L}_1(L<X) = \bar{L}_2(L>X)/2$			o			
Fracture criterion		$P' = G/$(Poisson ratio)					o	
Rupture criterion		$\sin A/2 \sim GX/PR_o$					o	
Break and tear criterion		Below rupture, no venting					o	
Holing, perforation		$DU^2/2 > G$					o	
Spalling criterion		$P > G$ G = tensile strength					o	
Initial fragment velocity		$Y_o/M_{tot} \leq U_o^2 \leq 6 Y_o/M_{tot}$	o o	o	● o			
FRAGMENT RETARDATION	Fragments slowed							
Shape factor, drag constant	↓	$B = M/L(\text{Area})D$, $c = \frac{1}{2}c_d D_o/BD_1$		o				
Retardation in air		$U = U_o \exp(-cZ/L)$	o					
Generalized drag		$UdU = -(a + bU + cU^2)dZ/L$	o					
Stopping power & cratering		$dK = -GdV$	o					
Relative effectiveness	Minimal	DX criterion	o		o			
Design of minimal shields	shields	17th DDESB Saf Sem	o					
TRAJECTORIES IN AIR	Fragments sail							
Fragment Energy and Numbers		FEN506, 17th DDESB Sem	o	o				
FEN CHart with gravity	↓	FRENCH		o				
Analytic solution		UNITRJ	o					
Explicit range equation		$X/L = \cos A \ln(1+(4qcU_o^2/gL)\sin A)/2qc$		o		o		o
Ground distribution		areal density $\sim \exp(-\text{constant} * R)$						o
High vs low angle fragments	minimal	Compare $(dA/dX(A)) \cos A$, both A's		o				o
Gunnery	barricade	rigidity of trajectory						o
SYMPATHETIC REACTIONS	Target reacts							
Minimum action criterion		$\int(E-E_c)dT > H_{min}$	o		o			
Sympathetic detonation		quasi continuum H(det)					o	
Deflagration, cook-off; hohlraum		H(deflr), H(burn)					o o o	
Correlation of tests	↓	$U = U_c(1 + b/D)^{1/n}$ $1 \leq n \leq 2$					o	
Data bank		P initiation vs % sensitive HE					o	
Multiple fragments		Loading $\cong 2P$			o			
Soft debris		Loading $\cong P/2$					o	
$P_d(50)$ predictions		$P_d = \sum P_i(X_i)$ (ergodic theorem)			o o			
Inhibitor plates and spacing		P(impact) < P(initiation)	o o		o			
Inhibitor capsule	Minimal				o			
Chain reactions in stacks	inhibitors	$P_d < 1/N$(nearest neighbors)			o			
Prudent stacking	nose-tail	distance, incidence, mutual shields	o o				o	
Optimized storage	loading mix	insensitive explosives as shields					o	

TABLE 2. DEFINITION SCHEME FOR UNIFIED DYNAMICS AND FOR CODING IN BASIC

<u>VARIABLES</u>

A	angle of trajectory $\angle$ A, incident shock $\angle$
$B = V/xyz = \frac{1}{2}\bar{Y} = (\int_0^x\int_0^y\int_0^z f(x,y,z)\,dx\,dy\,dz)/xyz$	bulk-shape-form factor
$C = (dP/dD)_Q^{\frac{1}{2}}$	speed of sound, of light, incompressibility
$D = M/V$	mass density, BD = ballistic density
$E = \int_V^{\infty} P\,dV$	total hydrodynamic energy in any volume V
F	external force
G	internal or body force, tensile strength
$H = \int(F+G)\,dX\,dT$	action integral
$I = MV$	momentum, inertia, impulse $dI = (F+G)dT$, electric current
J	normalized energy, electromagnetic forces
$K = \frac{1}{2} MU^2$	kinetic energy, organised motion
L	length, usually in direction of motion
$\bar{L} = (XYZ)^{1/3}$	root mean size = slope dlnN/dL in $\exp(L/\bar{L})$ distribution
M	mass
N	number of things, usually as an areal or spatial density
$\emptyset = (P-P_o)/P_o$	overpressure, normalized to local ambient pressure
$\theta = E/M$	temperature, energy/mass
$P = E/V$	absolute pressure, random divergent energy/volume curiosity
$\Pi = (P-P_o)/D_oC_o^2$	shock strength, natural units
R	radius of curvature, distance from center of symmetry
$S = dR/dT$	shock speed, phase velocity
T	time
$U = dX/dT$	material velocity
V	physical volume, but may be specific volume = 1/D scope
$W = \int_{V(P)}^{V(P_o)} P\,dV$	prompt energy or work
X	a horizontal distance, such as trajectory range, or a thickness
Y	a vertical distance, such as trajectory ordinate
$Y = \int(W+K)\,dV$	yield = prompt energy in arbitrary volume V
Z	idealized or curved length, such as trajectory path
$Z^3 = R^3(1+hM/M_o)$	phase space for effective mass M imbedded in ambient mass M_o

<u>SUBSCRIPTS</u> no subscript will usually indicate running variable

o = ambient state, 1 = initial state, 2,3,4... subsequent states or analogs

<u>NEARLY</u> <u>CONSTANTS</u>: for BASIC coding use capital letter with subscripts 9,8,7,6....

a	coefficient of zero order term, as in a +bU +cU² etc.
b	coefficient of linear term
c	coefficient of second-order (X^2) term such as drag
$c = c_d$	average drag coefficient needed to make "quickie" trajectory exact
d	usual differential, also coefficient of third-order (X^3) term
e = 2.71828	base of natural logarithms
$\epsilon = E/PV$	variable epsilon equation of state for non-ideal gasses
f(x)	usually, any function of the variable x
g	gravity, constant or not
$h = 6.06\ 10^{-27}$	erg sec, Planck's constant
$h = E/M\theta$	specific heat, ratio of specific yields in mass effect
h(x)	unitary operator, usually $\int h(x)dx = \int dx$ implies finite interval
$i = (-1)^{\frac{1}{2}}$	"imaginary number" also coefficient for an oscillatory response
$j = (-1)^2$	"sanity" operator
$k = -(d\ln P/d\ln V)_Q$	slope of adiabat on lnP-lnV coordinates
$\bar{k}$ = mean k	makes generalized equation of state locally exact
O = nearly zero	"DOIEC," <u>D</u>ividing by zer<u>O</u> <u>I</u>s <u>E</u>asy and <u>C</u>rafty
$q = -d\ln Q/d\ln Z$	logarithmic space derivative of any intensive variable Q
	non-linearity factor, to match linear approximation with exact expression
r = cos A	r^2 = correlation coefficient = correlated/uncorrelated variance
$s = ((x_i-\bar{x})^2/N)^{\frac{1}{2}}$	standard deviation of a sample N
$w = W/(P-P_o)V$	delayed energy factor, analog of ϵ

METHODOLOGY

The technology base is summarized in Tables 1 and 2; they are the hand-out[4]. Table 1 outlines this paper; Table 2 defines the symbols and their scheme. Table 1 is not perfect, but summarizes the body of analytical tools we used. Webster says a methodology is "a body of methods, procedures, working concepts, rules and postulates employed by a science,art or discipline...in the solution of a problem." Table 1, the technology base is such a list. It is a tool: by correlating all fields we can bring the whole technology to bear on new problems. It is also a discipline: it insures that what we profess in each field be consistent with what we profess in every other.

NESIP analyses are coupled as closely as possible with testing and were used to:

1. Select the Socorro test site by showing it would be adequate for NESIP.
2. Appraise the hazards, often to identify the significant threats,
3. Provide a basis for designing the test programs,
4. Analyze, appraise and extend the test results,
5. Invent and/or design mitigating devices when needed.

The methodology falls naturally into a logical sequence shown by column 1, Table 1.

1. Blast starts with an appraisal for the Maximum Credible Explosion (MCE) and then predicts the loading close-in (fragmentation) and far-out (1 psi).
2. Surface Effects and Interactions - how the geometry of the warhead and environment alters the initial blast loading.
3. Material response - how the warhead and targets yield under loading.
4. Break-up - The controlling parameters in fragmenting, rupturing or tearing.
5. Fragment retardation - how fragments are slowed in shields and in air.
6. Trajectories in air - analytic solutions are developed, including U^2 drag, to predict the areal density and terminal energy of fragments.
7. Sympathetic reactions - detonation, deflagration and burning; it includes a model and methods for controlling these reactions.

Inventions to mitigate these effects grew naturally from each analysis (Col. 2).

Column 3 shows a key idea, code or reference or equation for significant topics usually unique to the UTE-NESIP approach, i.e. new or preferred to previous methods. It was not obvious at the outset that these one word characterizations in Col. 2 --"(target) yields, fails, is slowed, sails, or reacts"-- would serve to organize the problems, and suggest different solutions. But it proved to be a useful way to organize the work and hopefully will be useful as a "how-to-do-it" reference using the present NESIP state of the art.

These analyses have been applied over a spectrum shown in column 4: torpedoes, missiles, rockets, shells, bombs and a number of sites and scenarios. NESIP problems have been solved by analyses, analogs or testing, whatever works. Sometimes, certain topics figured strongly in describing a particular project; sometimes the test project required development or modification of the theory; the circles show these key points of interest for both theory and test. Reading down, Table 1 organizes NESIP by concepts, referencing test projects across. We could turn the table sideways, reading the list of projects straight down and the same circles would then cross-reference the concepts reading across. Highlights of test results are given here and in other papers of this session.

BLAST LOADING

Virtually all our analyses start with a prediction of blast loading using UTE. The unified theory of explosions (UTE) is a way of describing any explosion:[5] nuclear, high explosive, gaseous, massive case - from the charge surface to far-out. The close-in predictions relate to fragmentation and sympathetic detonation. The far-field predictions are near 1 psi, because of the DDESB blast criterion.

Why use UTE, when dozens of hydrocodes, standard curves, nomographs, etc. abound? A compelling reason: only UTE includes such controlling facts of real explosions as:

- o mass effect of explosive and warheads; that depresses side-on pressure close-in, but sustains the pressure-distance curve far out.[5]
- o promptly available energy vs delayed energy due to dozens of effects like afterburning and reaction times we find in many real explosives.[5,7]
- o realistic equations of state, tested by determining hydrodynamics yields and predictions for nuclear explosions in air, underwater, and underground and the whole spectrum of military explosives and warheads.[6,8,11,14,15]
- o geometry effects for correlating tests in shock tubes, pressure tanks, etc.[10]
- o complex surrounds of explosion sites like magazines, berms, etc.[9]

UTE is practical, gets the job done; a run takes 1 second and costs about $1.00; UTE is an analytic solution, a hundred times faster and cheaper than hydrocodes; and no differencing code can match its speed and versatility for parametric studies. Above all, the same advantage as any analytic solution: you can see what is going on.

It has been almost universal practice to assign an equivalent weight to HE -- a single number, and a highly dubious one at that, being relative to TNT. With the same UTE codes by which nuclear explosions are evaluated with 1% accuracy, one finds that TNT releases about half the "classical" values 1080 or 1280 cal/gm. TNT releases about 600 cal/gm promptly, another 20% later by afterburning.[5] UTE uses absolute yields; on the same basis by which 1 KT nuclear means 10^{12} cal 1 KG means 10^6 cal, 1 gm means 10^3 cal, be it nuclear, point source, chemical or gas.

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[5]Porzel, F., "Introduction to a Unified Theory of Explosions (UTE),"NOLTR 72-209, Naval Ordnance Laboratory, Sep 1972, U.S. NTIS No. AD 758000.

[6]Porzel, F., "Height of Burst for Atomic Bombs 1954 - Part I - The Free Air Curve," LA 1664, Los Alamos Scientific Laboratory, Mar 1954, Library of Congress.

[7]Porzel, F., "Damage Potential from Real Explosions: Total Head and Prompt Energy," 16th Annual Explosives Safety Seminar, Hollywood-by-the-Sea, Florida, DoD Explosives Safety Board, Sep 1974.

[8]WT 9001, "Preliminary Hydrodynamic Yields of Atomic Weapons," Los Alamos Scientific Laboratory, Dec 1953, (Unclassified title, then SRD).

[9]NSWC TR 79-359, "Explosives Safety Analyses of the Machrihanish Magazine," Porzel, F., and Ward, J., U.S. Naval Surface Weapons Center, 1979, in publication.

[10]Porzel, F., "Correlation of Blast Simulators with a Unified Theory of Explosions," Proceedings of 3. International Symposium on Military Applications of Blast Simulators, Ernst Mach Institut (Freiburg) Schwetzingen, Germany, Sep 1972.

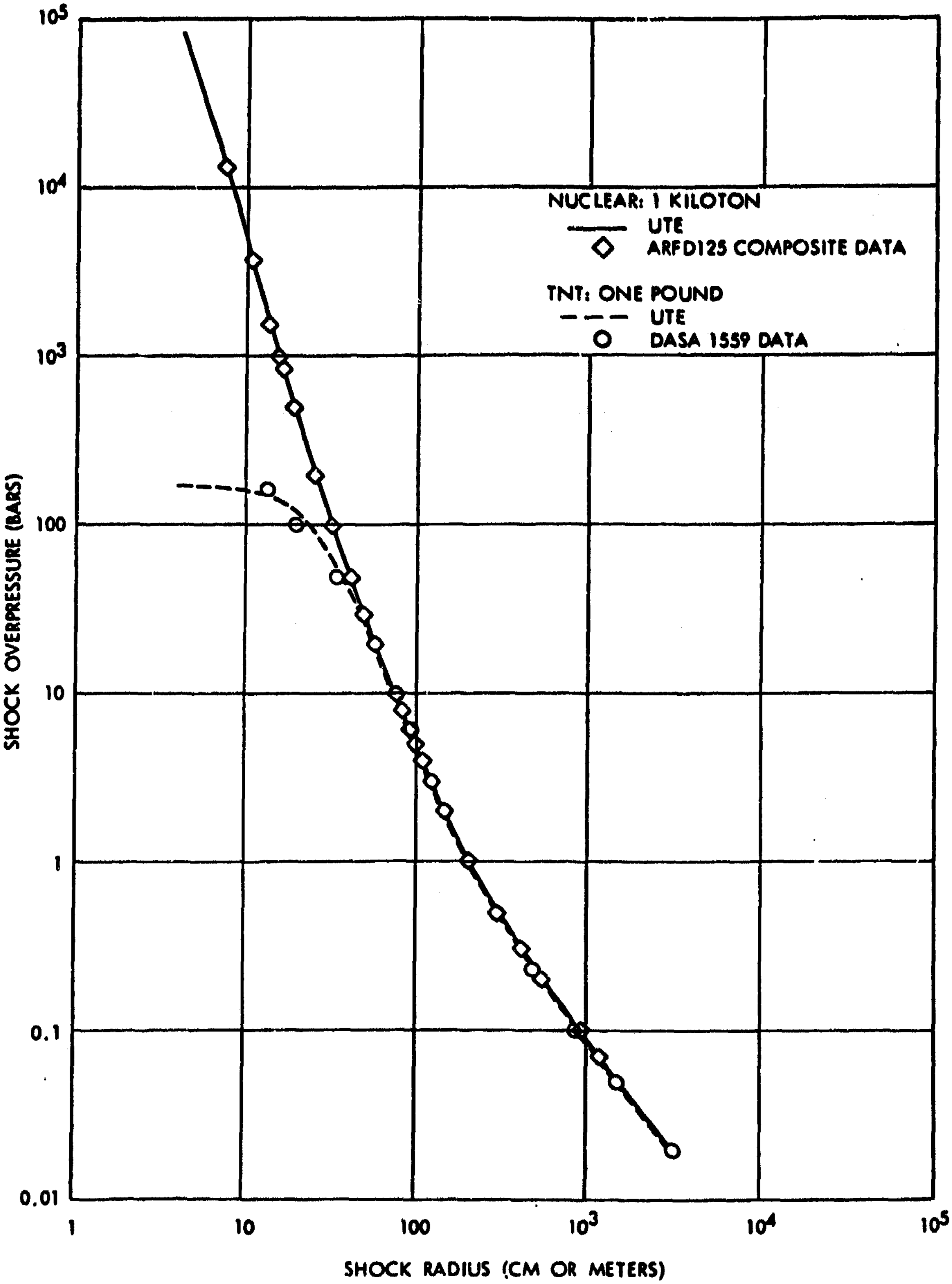


FIGURE 1 COMPARISON OF UTE PREDICTIONS WITH NUCLEAR AND TNT DATA

"Prompt, available" energy is a generic concept in UTE, it goes beyond entropy. "Available" refers to the energy realized by expanding back to ambient pressure P_0. "Prompt" means only that fraction delivered fast enough to support the shock ahead. For many processes, we need to distinguish between "initial" and "delayed" yield. The "initial yield" concept simply recognizes that not all of HE is instantaneous. In afterburning and aluminized explosives in particular; a substantial fraction of the energy is released too late to affect detonation, even though it is released quickly enough to be counted in "equivalent weight." Thus, an initial yield exists, and applies to: detonation, wall and case velocity, sympathetic detonation, fragmentation, early hull rupture, and underwater shock. A delayed, or final yield exists and is better related to "equivalent weight". It applies to afterburning fraction, airblast, underwater bubble, quasistatic pressure in enclosed spaces, late hull rupture and venting processes.

Five formal UTE codes are available, depending on the application which is sought. The analytic solution, ANS, derives detailed wave forms and total energy[6,8] based on a set of measured data at the front of fireball or strong shock. Direct Evaluation of Blast (DEB) simply sums the energy implied by measured data.[5] Direct Scaling (DSC) averages the local apparent yield implied at each pressure by comparing the measured radius with the theory for a trial absolute yield.[5] It serves well as a statistical analysis for large masses of measured data that would be prohibitively costly with classical scaling methods. Damage Predictions, UTEDMG calculates key damage variables vs distance[7]. UTEDMG is probably the most widely used of all the codes for NESIP applications. Given the initial yield, ambient conditions, and mass of explosives and surrounds, it calculates side-on, dynamic, reflected pressures, impulse and energy flux for any distance from the charge surface to distances arbitrarily far out. The FORM factor B in UTEFORM, as shown, is simply: average/peak energy in the wave. A new method, it will be ideal for non-spherical explosions, variable yield etc. So far, it correlates with nuclear fireball data to a fraction of a percent in radius, and is far within the experimental uncertainties for non-ideal high explosives.

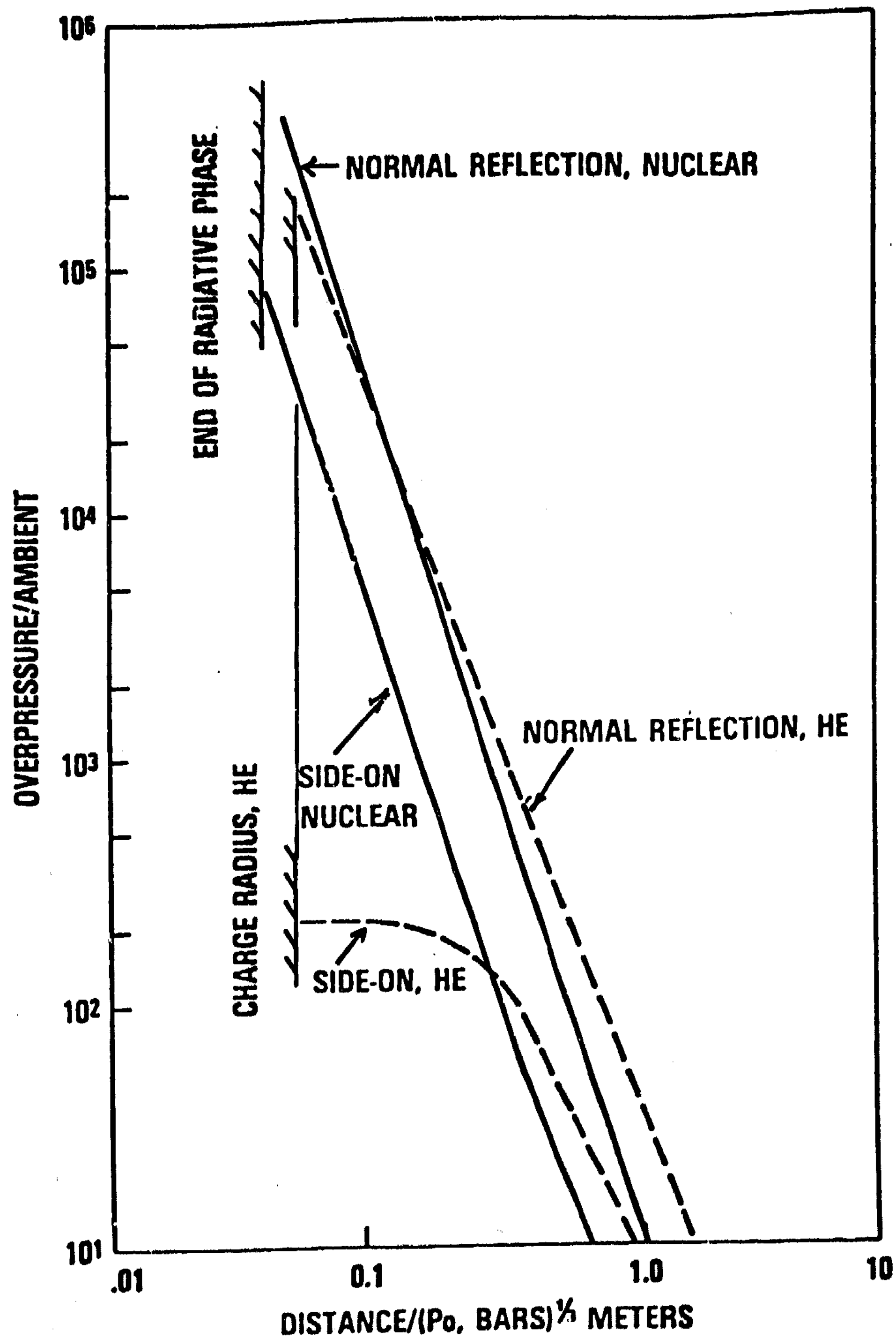
Figure 1 is from NOLTR 72-209, shows the excellent correlation of data with UTE. The full line is the theory for nuclear, the diamonds are a composite of measurements. The dashed line is the theory for TNT, and the circles a compilation of TNT data. As here, the correlation is often too close to be shown by a pressure-distance curve. Instead, both DSC and UTEFORM calculate the standard deviation, a few % in yield. Figure 1 also shows how closely one <u>pound</u> of TNT scales with 1 <u>KT</u> nuclear far out.

Fig. 2 compares side-on and reflected pressure from 1 kg, HE and nuclear. The HE actually weighs 1 kg but the (scaled-down) nuclear would weigh about 1 gm. Note the drastic drop in side-on pressure, from 80000 bars (nuclear) to 200 bars (HE). This reduction is entirely due to the mass effect of the high explosive. But this energy is not lost, as the Gurney-Fano corrections imply, just released later. This reduced pressure also reduces the dissipation close-in so eventually the HE curve crosses the nuclear curve; HE is a more efficient explosion far-out. Note the reflected pressures are nearly the same for both HE and nuclear. These are nearly a thousand times the side-on pressure for the high explosive. Using classical shock theory, the reflected pressure would only be about 8 times. This large ratio again is due to the mass effect of the high explosive.

It is this ability of UTE, to predict accurately the loading close to the charge that accounts, more than any other technique, for the success of the technology base to successfully model fragmentation, failure modes, surface interactions, sympathetic detonation from high explosives, and to design inhibitors.

FIGURE 2

PRESSURE - DISTANCE FOR 10^6 CAL = 1 KG, HE OR NUCLEAR



SURFACE EFFECTS AND INTERACTIONS

Surface interactions with the blast greatly reduce the side-on pressure due to thermal radiation and mechanical effects such as dust loading, surface roughness. A comprehensive theory was developed for these effects on nuclear weapons and was the basis for their tactical employment, via height-of-burst curves.[11] Whereas classical blast theory identified two types of reflection: regular and Mach, LA 1665 identified five: regular, transition, two kinds of Mach and hemispherical. Transition reflection is important because it controls the knees in the HOB curves. It places an upper limit on pressure multiplication, regardless of regular or Mach. Mechanical effects occur too for HE: however the thermal effect is less drastic. Simplified calculations for height-of-burst exist, adequate for safety studies.

Of all interface mechanisms, venting can exert the strongest effect. See Figure 3. It refers to the strong tendency of blast energy to flow into rarified media. Common sense tells us the qualitative fact; energy flows best into tunnels, but cannot tell us the enormous quantitative effect by which it does so. Figure 3 shows that the rate of work in any medium per unit area and time is $dW/dt = PU$, i.e., a piston at pressure P advancing with material velocity U. Comparing different media, density and compressibility compound their effect; the net result can be 1000:1 preference to flow into the rarified media. An example for submarines: if the space above the torpedo magazine were open, the explosion would vent out the top carrying most of the energy and fragments too. The blast and fragment hazard would extend beyond a thousand feet. A real submarine is packed with internal equipment that suppresses venting. The hazard arcs were found less than 200 feet for both blast and fragments.[31]

For flow calculations in complex geometries, two simplifications arise. If the case completely surrounds the HE, then energy is conserved during transfer; if not, venting occurs into open spaces, but momentum is still conserved, and we must include the mass effect to describe the outgoing blast wave. Since much of the energy of HE is carried by its explosion products, the vented fraction above an earth fill, an underground or underwater explosion will determine the fraction of energy going into air blast. Venting has had a long and important history in the safety know-how of UTE: Thirty years ago, the decision to fire the first H-bomb on the ground rested on a theory showing that only .1% of the energy would go into ground shock.[8,12] Reactor safety technology rests strongly on venting to redirect blast energy.[13] The venting concepts were successfully applied in many NESIP projects:

- the vented fraction of an earth covered magazine (Machrihanish studies)[9]
- the air blast from a venting submarine (New London project)[31]
- design of minimal shields (Mk 16 torpedo)[16]

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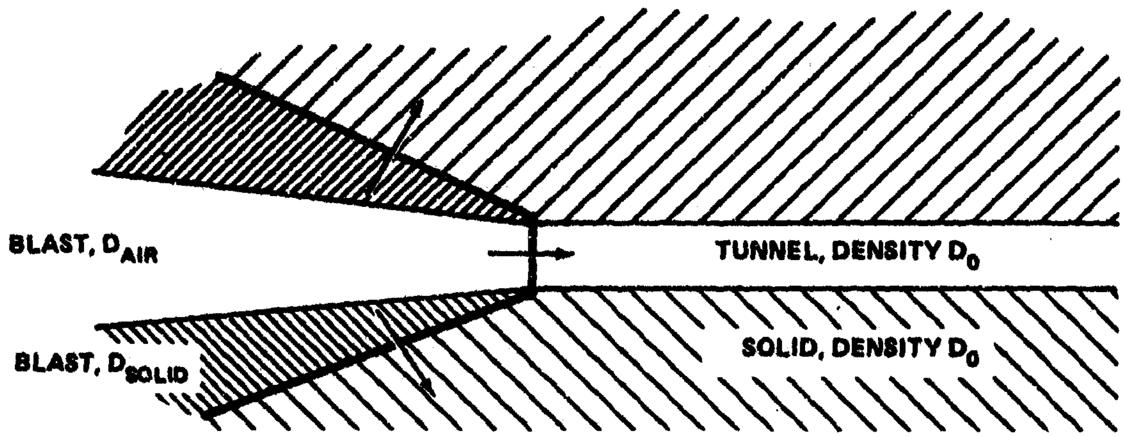
[11] Porzel, F., "Height of Burst for Atomic Bombs 1954 - Part II - Surface Effects," LA 1665, Los Alamos Scientific Laboratory, Mar 1954, Note: Both volumes, LA 1664 and 1665 are available from U. S. Library of Congress.

[12] Porzel, F., "Soil Pressure and Energy Transfer on MIKE Shot," LA 1529, Los Alamos Scientific Laboratory, Oct 1952. (then SRD)

[13] Porzel, F., "Hydrodynamic Problems in Reactor Containment," UNP434, United Nations Second International Conference on Peaceful Uses of Atomic Energy, Sep 1958.



$$\dot{W} = PU = \sqrt{\frac{1}{D_0} - \frac{1}{D}} = \sqrt{V_0 - V} \quad \Big\} \text{ IN EACH MATERIAL}$$

$$\frac{\dot{W}\ (\text{AIR})}{\dot{W}\ (\text{SOLID})} = 1000/1$$

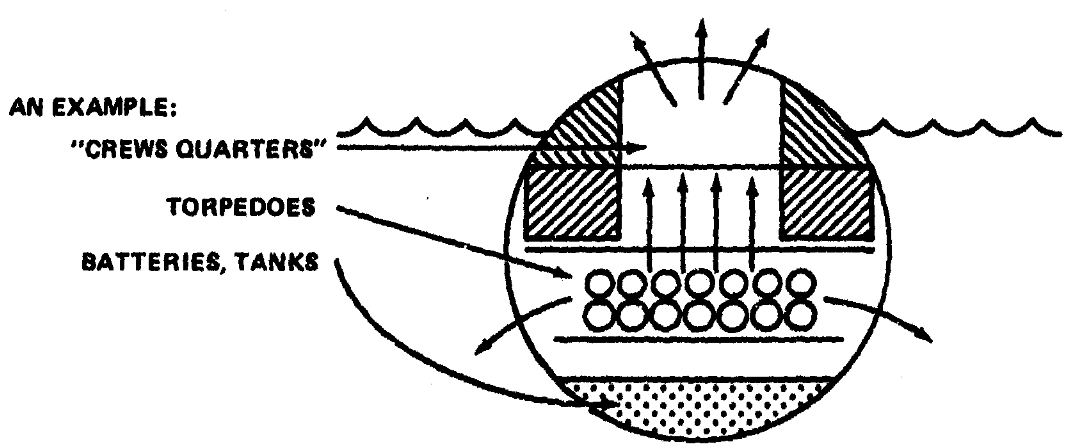


FIGURE 3 CHANNELING, VENTING OF ENERGY

MATERIAL RESPONSE

How are materials altered upon application of the blast loading?

If we are to solve all safety problems, i.e. involving many different materials, we require an equation of state, if only approximate, that applies to all media. Some material here is not new to NESIP, they were developed for pioneering work: analyses and tests for yields in air[6,8], for the first deep underwater nuclear explosion[14] and the first contained underground nuclear explosion[15]. Current NESIP problems are solved with these techniques, proven out long ago by nuclear tests.

Let us first define a dimensionless natural unit for pressure as in UTE[5]:

$$\psi = (P-P_0)/D_0C_0^2, \text{ overpressure/bulk modulus}$$

Only two parameters are used: ambient density D_0, ambient sound velocity C_0, and a remarkable simplification then arises. For weak shocks, $\psi \ll 1$, and

overpressure = overdensity = material speed = supersonic shock speed.

$$\psi = P-P_0/D_0C_0^2 = D/D_0 - 1 = U/C_0 = S/C_0 - 1$$

In other words, all these quantities are not only proportional to each other but each has the same numerical value ψ for acoustic waves and weak shocks.

From first principles an approximate but generalized equation of state becomes

$$\psi = \left[(D/D_0)^K - 1\right]/K$$

that not only applies to gases, fluids and solids but is insensitive to K. Here, K is nearly constant, the local adiabatic compressibility K = d lnP/d ln D. By defining K as an average value from D_0 to D, the equation can be made exact. For gases, K = usual values; for solids and liquids a good approximation is K = 7.

For homogeneous materials and small ψ the waste heat Q (see next page) becomes

$$Q = \frac{K+1}{12}\psi^3 \text{ for gases,} \quad Q \simeq \frac{K(K+1)}{12}\psi^3 \text{ for dense media}$$

Furthermore, in the blast wave itself, the average energy on the interior is well related to the peak value at the shock front by a form factor F such that

$$\frac{Y}{(4\pi/3)R^3(P-P_0)\alpha} \equiv F = (1/3)\left(\frac{\psi}{1+\psi}\right)^2 .$$

All these are reasons why a unified theory of explosions is possible, and they indicate the way in which explosions in different media can be treated quantitatively.

Other properties follow from the non-linear nature of the equation of state.

At high strain rates, some say the stress-strain curve is anomalously high; but the shock equations suggest the "extra energy" is kinetic energy and waste heat, $E-E_0 = W + K + Q$, and the generalized equation of state can continue to apply.

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[14] Porzel, F., "Close-in Time-of-Arrival of Underwater Shock Wave," Final Report, Project 4.4 Operation WIGWAM, WT1034, 1956.

[15] Porzel, F., W. C. Anderson, "Close-in Time-of-Arrival Measurements for Yield of Underground RAINIER Shot," Project 23.1 Operation PLUMBOB, Jul 1959.

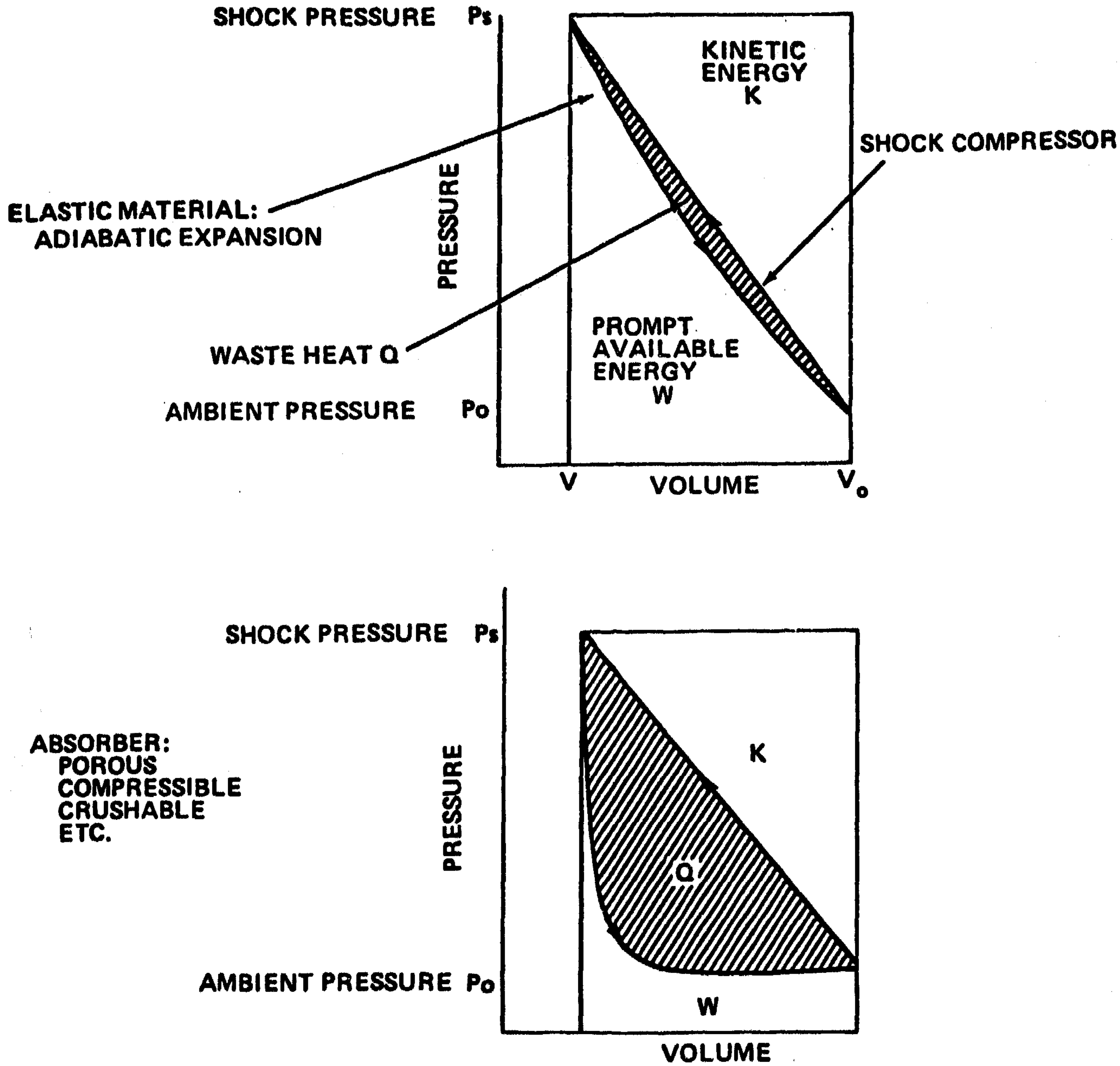

FIGURE 4 WASTE HEAT CONCEPT

COMPARISON BETWEEN ELASTIC MATERIALS AND GOOD ABSORBERS

Figure 4 illustrates the waste heat concept and basic idea for blast shields[13, 16].
The waste heat concept is a simple way of describing, better than entropy, a separation between prompt energy and energy delayed by dozens of processes.[5] Material initially at the state P_0, V_0 is shocked up to the state P,V (straight line) but expands behind the shock by faster decay along the curved path shown. For solids and liquids, it returns essentially to its original state, P_0, V_0. The sliver-shaped area is the delayed energy Q left behind in the material. For elastic materials, the two paths are nearly identical; no energy is "lost". But for highly compressible or porous materials which "crush down" readily, it is easy to see that about half the energy being delivered to the shock is continually being transformed to delayed energy and thereby "lost" to the front.

One main NESIP application of waste heat: the blast shield for Mk 16 torpedoes. It was essentially a sand wall, 1 foot thick: it also stopped fragments[16]. (See Fig. 18)

About ten early power reactors built in the United States contain blast shields designed using the waste heat concept to protect the reactor from internal explosion[13]. Three Mile Island had no shield, but the worry was the same: "metal-water reactions". The USS nuclear merchant ship Savannah had a redwood-steel blast shield in it, where it was euphemistically labelled a "collision mat". It would do that too.

The last two items under "Material Response" are significant for scaling results, and they are a logical transition to the next topic of "Material Breakup." Owing to non-linearity, materials become stronger with increased confinement instead of responding constantly, as Hooke's law, or the modulus D_0C_0 imply. But they fail in extension, not directly related to some inherent modulus but due to the greater chance of finding some weaker defect in a larger sample. As a consequence, we expect to find, and do, for some materials like HY80 steel, that the % elongation is not constant with sample size, as Hooke's law suggests, but the % decreases with sample size; in short the larger sample seems more brittle. On the other hand, larger structures embody much better metallurgy and fabrication say in comparing full scale submarines with test models. For similar reasons of scale, the energy required to fracture a large sample increases, because the energy required is proportional to the new area created, a size factor even though the work done per unit area, $P\Delta L$, may be characteristic of the material.

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[16] Porzel, F., "Design of Lightweight Shields Against Blast and Fragments," Minutes of 17th Explosives Safety Seminar, DoD Explosives Safety Board, Denver, CO, 1976.

BREAKUP AND FRAGMENT FORMATION

Given the blast loading and material, how does specific warhead case or target fail? Into what sizes of fragments and how are the sizes distributed?

Of course, the controlling facts are the strength of the shock and of the target. Given a shock strong enough to fracture, the problem is clearly statistical because common experience shows that such fragments vary randomly in size.[16] For generality and reliability we use as few assumptions as are necessary. A minimum set of assumptions appear to be:

1. The number of new fragments created dN is always proportional to the number of fragments N already existing: $dN \sim N$
2. The fracturing will start at some weak point; the chance of finding a weak spot is proportional to the volume transversed: $dN \sim$ area x dL.
3. The number of new fragments will be inversely proportional to energy of fracturing, which is proportional to the new area created; $dN \sim 1/\text{area}$.

Taken together, these assumptions lead to dN = - constant * N dL; integration gives

$$N(>L) = N_o \, e^{-L/\overline{L}},$$

a familiar "straight line on semi-log paper" with intercept N_o and slope $1/\overline{L}$. This resembles but differs from the specific Mott formula with $N = N_o e^{-\text{constant}\, M^{1/2}}$ and more useful for predictions than a general 3 parameter form $N = \beta e^{-\left(\frac{M}{Y}\right)^{\alpha}}$.

Figure 5 shows an early correlation with arena data from 500 and 750 pound bombs. We also find good correlation in such diverse things as

- o secondary fragments from a truck, (Figure 6)
- o large torpedo fragments found at 500' to 1000' (Fig. 7)
- o the pieces of a broken ceramic luncheon plate which fell on a road (Fig. 8)

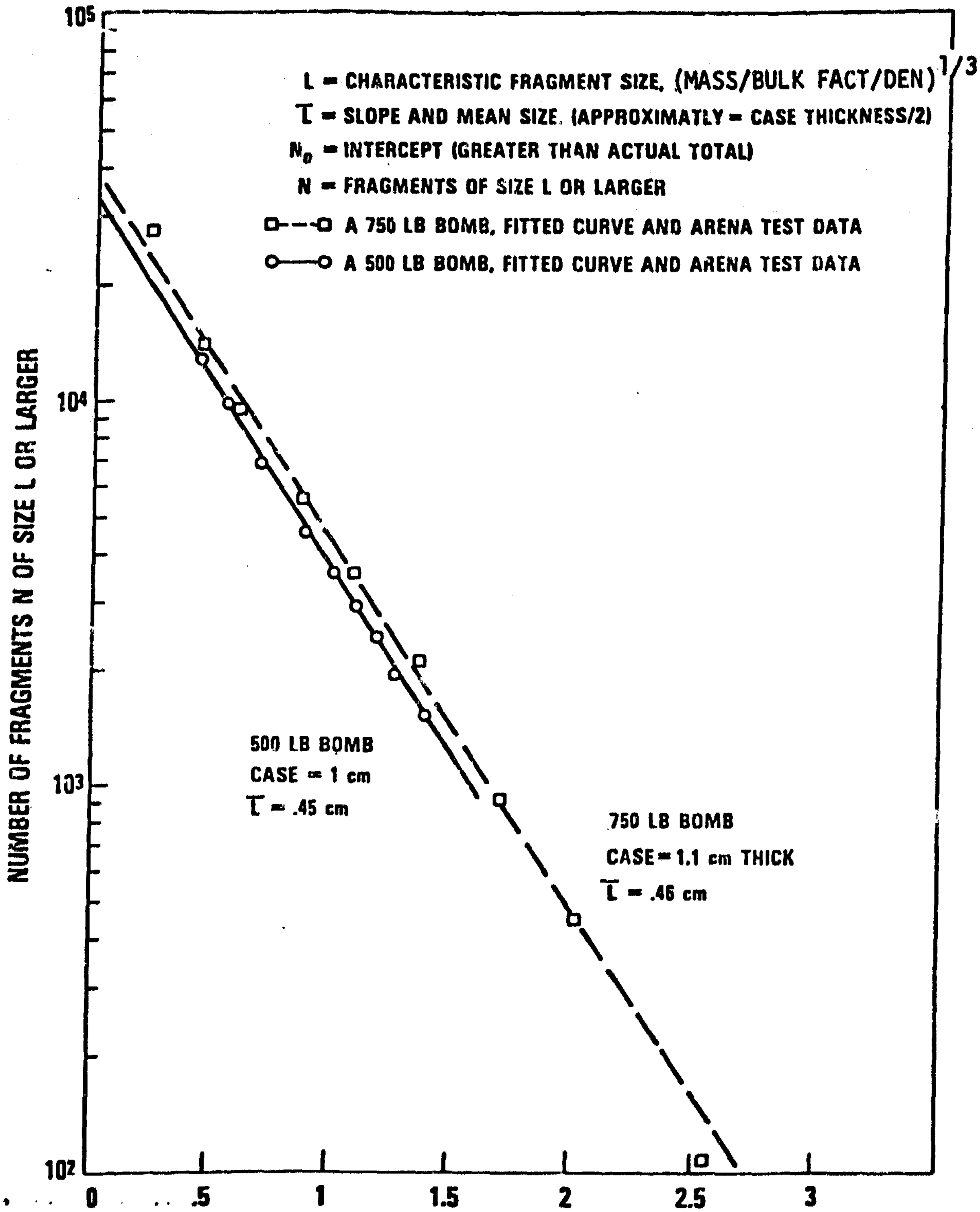
Figure 8 is a single sample but is amusing as an extreme test of the theory. When the plate fragments were first weighed and plotted ($M^{1/3} \sim L$), the result indicated N_o = 24 was larger than the number recovered, nor was it a straight line. When the plate was put together, the holes, - obviously missing fragments - showed the original numbers did fit on a straight line, and consistent with N_o=24.

Such correlationas are fun but ought not be surprising with assumptions so general. We cannot know details and did not specify a priori N_o, slope $\overline{L}$, or size range. But the basic assumptions do apply and are sufficient to specify a semi-log fit. If they work for a broken plate, one is confident they will work for a new warhead.

FIGURE 5

TEST AND APPLICATION OF FRAGMENT DISTRIBUTION HYPOTHESIS

$N = N_0 e^{-L/\mathcal{T}}$



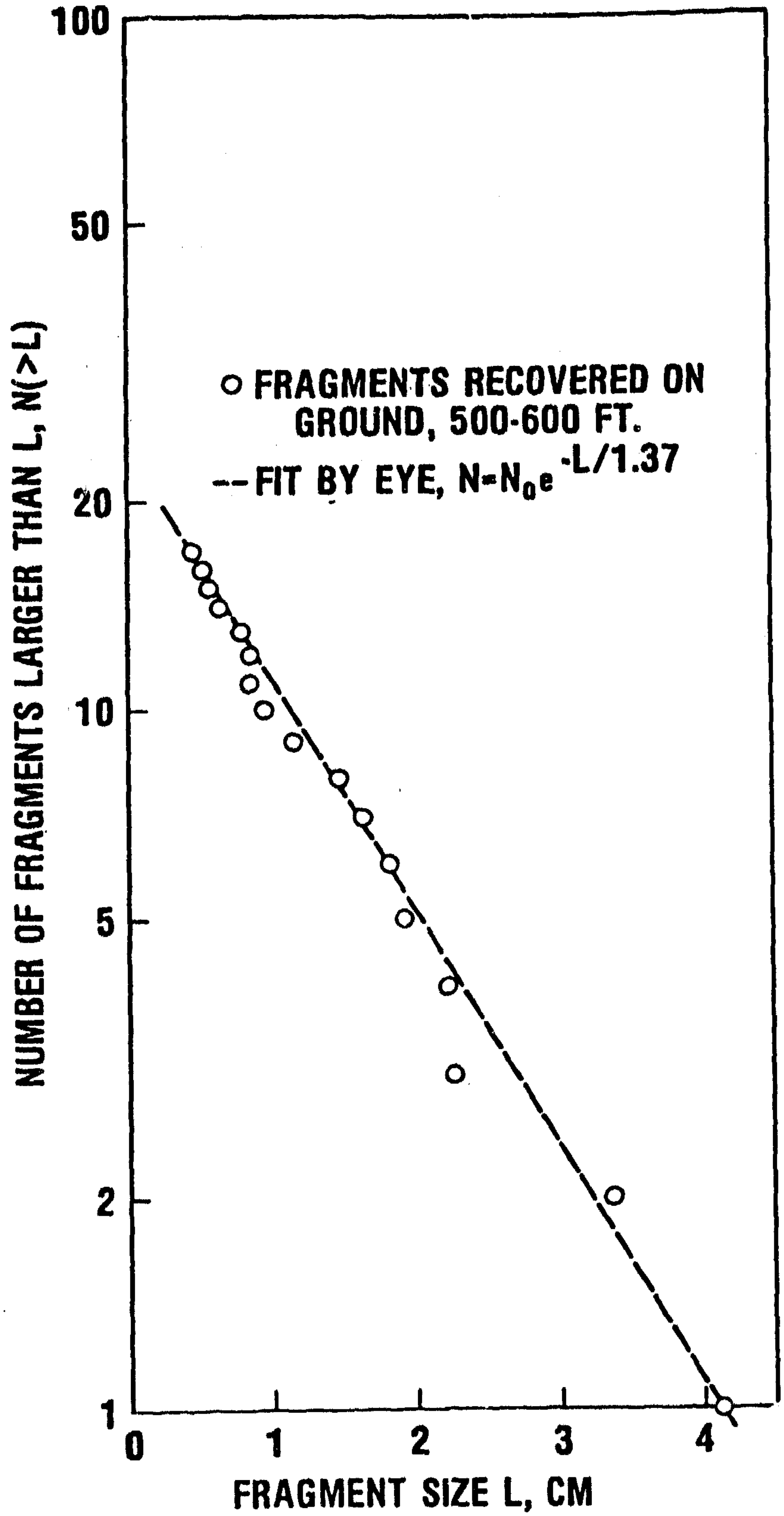


FIGURE 6. TRUCK FRAGMENT SIZE DISTRIBUTION

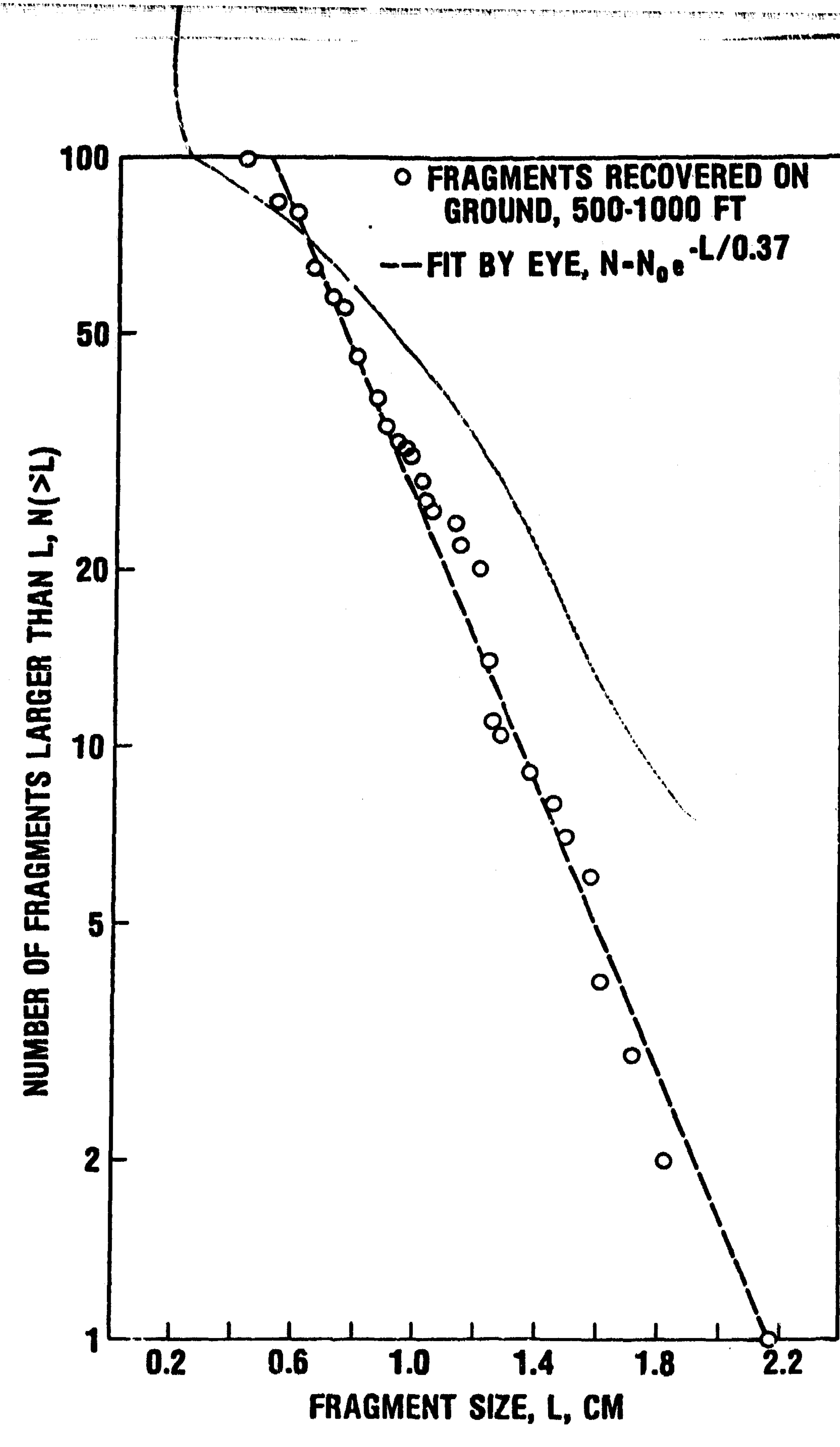


FIGURE 7 MK 16 TORPEDO FRAGMENT SIZE DISTRIBUTION

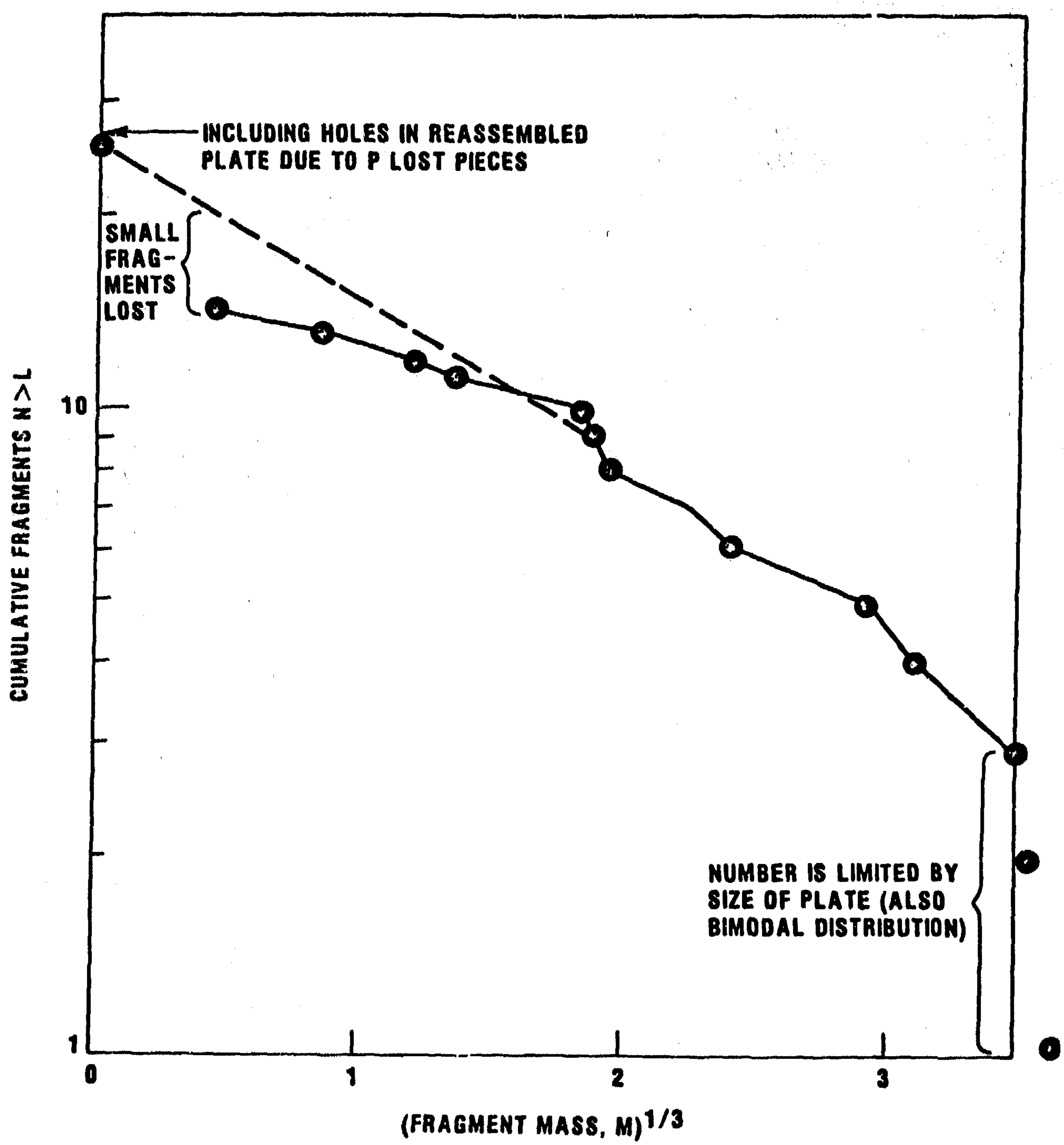


FIGURE 8. FRAGMENTS FROM A BROKEN PLATE

Note that $N_0e^{-L/\bar{L}}$ only fits the curve; common sense physics prescribes the limits. Fragment sizes cannot extend down to L = 0; too much energy would be required. Fragment sizes cannot extend to L = ∞; that is larger than the warhead! Thus, the fitted curve applies to a limited range of fragment sizes and actual limits L_{min} and L_{max} should be used for integrating total mass, numbers etc.

One expects that the proportionality constant in dN = constant*NdL will differ for fragments smaller than the cases thickness X as opposed to those larger than X, a 3-D vs 2-D problem, with the case surface as a built-in weakness, biasing $\bar{L}$. This suggests a bimodal distribution, as shown in Table 1, a steeper slope for large L. Arena data support this idea but data are usually too sparse to define two slopes. For practical purposes, the dominant $\bar{L}$ (steeper slope) works well for both domains.

For predicting $\bar{L}$, it is reasonable to suppose the mean size $\bar{L} \sim$ case thickness It would, but as argued above for ductility, the larger size appears more brittle. Hence we expect, and arena data for Mk 80 series bombs indicate, that $\bar{L} \sim X^{1/2}$.

The initial stress from shock or fragment loading controls the mode of failure. Accordingly, Figure 9 shows a hierarchy of "fragments", from high to low stresses:

1. Fracturing, like a bomb. The shock is so strong the case fails locally. The pressure needs be about 3 times the tensile strength G. More definitely, the criterion is P ≃ G/Poissons ratio.
2. Rupturing, like a pressure vessel. The shock is too weak to fracture, but the accumulated load will cause failure over some angular sector A. For spherical sectors $\sin A/2 \simeq 2\ GX/PR_0$, for cylinders $\sin A/2 \simeq GX/PR_0$.
3. Break and Tear, like a paper bag. Even though the shock is too weak to rupture the case as a whole, it can and probably will fail locally due to fragment impact or weak points. Once that happens, and if the stress is not relieved by venting, tearing is almost inevitable.

The spatial extent of the loading also controls, proved by fragment holes. The local stress is characterized by the "dynamic pressure" of the fragment. Here again we need to distinguish between:

1. Holing (perforation). The fragment is fast enough to punch a hole, but the stress is too brief and the blast too weak to sustain tearing.
2. Spalling. The fragment is too slow, or the target too thick to be perforated but the rarefaction on the back side does exceed the tensile strength.
3. Cratering, the fragment velocity exceeds the tensile strength criterion, but the target is too thick to permit perforation or spalling.

For initial fragment velocity, the Gurney-Fano factors specify a single number. Arena data often list but a single number for all fragments in each polar zone. When jetting occurs in stacks, some assume that same velocity for the whole stack. (Jetting in stacks is a separate effect, shown as a reflection process on Table The UTE model, on the other hand, treats a spectrum of velocities, even for one round. In UTE, we assume energy is partitioned equally among total mass present, case + HE. For strong shocks, that energy is equipartitioned between internal and kinetic energy. Setting the kinetic energy $\frac{1}{2}MU_0^2 = Y_0/2$ the proper average velocity gives $U_0^2 = Y_0/M$. But the velocity of the outer layers are enhanced by two effects Gurney-Fano omits.

1. The blast energy is both internal and kinetic, and peaked at the front.
2. When the shock emerges from the case, a strong rarefaction moves backward which converts all the local energy to kinetic, about doubling it.

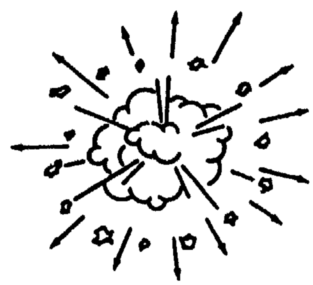
With corrections for waveforms, the fastest fragments go with $U_0^2 \simeq 6\ Y_0/M_{total}$.

This spread, average to peak, $Y_0/M < U_0^2 < 6\ Y_0/M$ replaces one Gurney velocity $\sqrt{2E}$, but does not require a different -Fano- factor for each value of C/M.

- **FRAGMENTATION (LIKE A BOMB)**

$$P_c \cong \frac{G}{\sigma} > 240000 \text{ PSI}$$

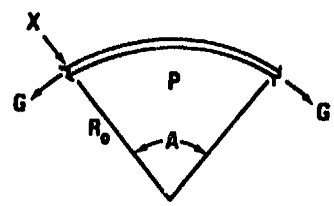
(FOR MY 80 STEEL)



CATASTROPHIC FAILURE
SMALL FRAGS

- **RUPTURE (LIKE A PRESSURE TANK)**

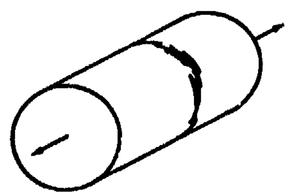
$$\sin A/2 \sim GX/PR_o$$



VIOLENT VENTING
LARGE SECTORS

- **BREAK & TEAR (LIKE A PAPER BAG)**

"ZIPPERING" DUE TO: FRAGMENT, WEAK SPOT, CORNERS



INERTIAL CONFINEMENT
BOTH BLAST & FRAGS

FIGURE 9. MODES OF FAILURE

FRAGMENT DECELERATION

Given a fragment at velocity U, how much is it retarded by shielding or in air? U^2 drag is the controlling mechanism of course; its familiar parameters include velocity U, fragment size and shape, densities of air D_o and of fragment D. Despite the great variations in natural fragments, we find two simplifications:

1. "Shape factors" B for most real, tumbling fragments are all about 1/3.
2. The deceleration depends only on length L in direction of travel and is independent of the cross-sectional area A at every instant.

The shape factor B is defined through the requirement that mass M = BALD, or volume V = BAL; volumes of most such shapes are $V \approx (1/3)$ AL, this is exactly so for pyramids and cones etc., approximately so even for a tumbling cube. Regarding drag, the drag force is $F = \frac{1}{2} c_d A D_o U^2$ (c_d = drag coefficient, A = area) the deceleration itself is given by Newtons law, but independent of A because

$$\frac{dU}{dt} = U\frac{dU}{dZ} = \frac{F}{M} = \frac{\frac{1}{2} c_d A D_o U^2}{B\ A\ D\ L} = \frac{\frac{1}{2} c_d D_o}{B\ D}\frac{U^2}{L} = \begin{bmatrix}\text{dimensionless}\\ \text{nearly constant}\end{bmatrix} * \frac{U^2}{L}$$

Of course, for tumbling fragments, L, A and c_d all change rapidly, but the time average of L is surely close to $V = BL^3$, so that $L = (M/BD)^{1/3}$. Thus the average length L is given simply by its mass M, density D and B. This formulation is particularly useful since we saw in the last section that for a wide variety of fragments, the size distribution was also characterized by the fragment length L.

The decay from initial velocity U_o with range Z then becomes

$$\frac{1}{U}\frac{du}{dZ} = -\frac{c}{L}\ ,\ \text{which integrates to}\quad U = U_o\, e^{-cZ/L}$$

where $c = \frac{1}{2}\frac{c_d}{B}\frac{D_o}{D}$, dimensionless number, slowly varying or nearly constant.

For small velocities, U^2 cannot control drag; it says U>0 until Z = ∞!
For a constant resistance, like crushing strength, the retardation becomes

$$U\ dU/dZ = -\ \text{constant}/L,\ \text{leading to}\ U^2 = U_o^2 - \text{constant}\ Z/L$$

At higher velocities, the retardation could be due to a viscous force dU/dt = bU, with b = constant, UdU/dZ = bU/L, leading to $U = U_o$ - constant Z/L. Complex general retardation formulas may apply, but from the dimensions of F/M the decay can always be written in terms of the dimensionless ratio Z/L.

When the resistance is constant, say in partial penetration of armor plate, the work done in decreasing kinetic energy dK is always simply proportional to the tensile strength of the plate and new volume of the crater.

$$dK \cong -GdV \qquad \text{which leads to}\ K_o = \tfrac{1}{2}MU_o^2 = GV/2$$

Thus the crater volume is a direct measure of the original kinetic energy For further reasons, such as tumbling, knife-edge entrance, failure modes, this is not an exact or a simple way to measure the initial fragment velocity. But it is functionally correct, gives the energy without knowing fragment size(!) and gives a better fit than the usual method of relating impulse with volume.

Since the stopping power does involve the density D of the stopping material, it is a rough but convenient correlation to measure their relative effectiveness by the assuming density D * penetration X = constant. This is the DX criterion.

A natural outgrowth of these considerations is the minimal shield[16].
The main function of the shield is to stop primary fragments from the case.
Almost any material is as good as any other having the same DX = constant.
But blast loading and primary fragments are also the source for secondary fragments.
The same shield is well suited to reduce all three: blast, primary and secondaries.

The blast shield embodied several other concepts: (Figure 18)

- o minimal area of shield, looking outward from the explosive to maximize the area for venting blast energy in non-hazardous directions
- o maximum stand-off for a given area shield from the explosive to exploit the divergence of the blast and minimize the momentum intercepted
- o a porous material -- like sand -- to absorb energy by waste heat processes. (It goes without saying, sand is literally dirt cheap, too!)

Finally, it is not necessary to stop the primary or secondary fragments, but only to slow them to velocities so they become non-hazardous at 500 feet or so.

We turn now to fragment trajectories in air, an excellent retarder for fragments.
(Not only because it is cheap, there is also lots of it!)
Using the DX criterion, 500 feet of air at .00129 gm/cm^3 is as good as 5 in of sand at 1.5 gm/cm^3.

TRAJECTORIES IN AIR

Four useful and powerful tools have been developed for trajectory problems. All are analytic, but codes are convenient to do the drudgery:

- FEN for Fragment Energy and Numbers, radial motion w/o gravity (Fig. 10)
- UNITRJ, an analytic solution for U^2 drag and gravity forces (Fig. 11)
- QUICKIE, a one-step version of UNITRJ
- FRENCH = FEN + gravity, for FRagment ENergy and Numbers CHarts.

The same advantages of speed and cost accrue here as to all analytic solutions. But mainly one gains insight and versatility that a differencing code cannot give. Both FEN and UNITRJ were described in the 1976 seminar[16].

FEN starts with the yield of the bomb Y_o, the total mass and mean fragment size $\bar{L}$. The key idea: map the fragment hazard using the DDESB criteria as axes. Number of lethal fragments is the ordinate, the energy is the abscissa (Fig. 10). A hazardous zone is immediately apparent; the box where both criteria are exceeded. Most lethal fragments arrive at angles so flat that gravity is inconsequential. FEN neglects it. The advantage: we can map the whole field at once to determine the range where the criteria are exceeded and what size fragment is most critical. The FEN chart is reliable because it is so strongly pegged to average values. It states the limitations imposed by conservation of mass, momentum and energy.

The FEN chart procedure is also flexible, permitting simple powerful changes:

- Correction for different number of bombs.
  Simply increase the ordinate by the appropriate number of bombs, because the areal density $N = N_o \exp(-LZ/\bar{L})$ is always proportional to N_o. If the stack is simultaneously detonated, or other stack interactions occur, a different, appropriate factor applies, usually less than the number of bombs.
- Correction for a variation of areal density of fragments with polar angle:
  Simply increase the ordinate by the appropriate ratio for that polar angle. Same reason as above: the areal density is always proportional to N_o.
- Correction for variation in initial velocity with polar angle:
  Simply shift the abscissa the proper amount, right or left. The terminal energy $E = E_o \exp(-2cZ/L)$ is proportional to E_o.

By basic assumptions, FEN is conservative, calculates areal densities of fragments normal to the trajectory, an overestimate for both horizontal and vertical targets. But given a simple trajectory algorithm (see below) it is straightforward to resolve a FEN areal density into its horizontal and vertical components. FRENCH is such a "second-generation" code, combining FEN with gravity effects.

The unique feature of UNITRJ and its derivation are due to choice of variables: length Z along the trajectory, and the local trajectory angle A. (See Fig. 11). When drag and gravity forces are resolved along these axes one derives

$$Z = \frac{L}{2c} \ln\left[1 + \frac{4c}{gL}(U_o \cos A_o)^2 \left[f(A_o) - f(A)\right]\right]$$

$$U e^{cZ/L} \cos A = \text{constant} = U_o \cos A_o$$

where

$$f(A) = \frac{\tan A}{\cos A} + \ln\left(\tan A + \frac{1}{\cos A}\right)$$

As a result, relations between path length Z angle A, velocity U and time T are all explicit and exact.

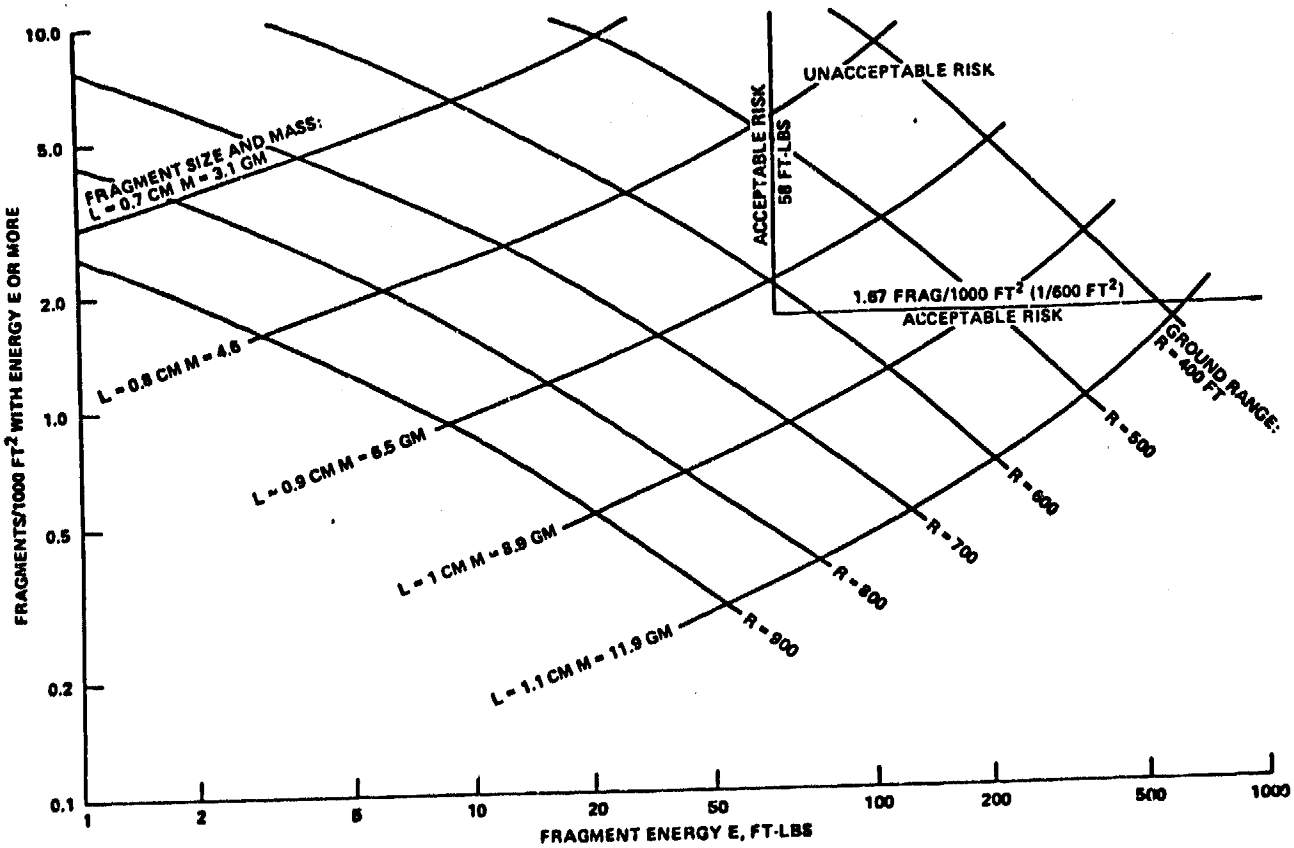


FIGURE 10. FRAGMENT ENERGY AND NUMBERS (FEN CHART)
TYPICAL FRAGMENTS, 3400 f/s, TWO WARHEADS
TOTALS: 1500 LBS HE, 1000 LBS CASE, 0.36 CM THICK

In practice, the range X, ordinate Y, and time T are calculated from differentials

$$dX = dZ \cos A,\ dY = dZ \sin A,\ dT = dZ/U\ ;$$

This can be done precisely and in bold steps because Z and A are known exactly. Integration in bold steps is also required when the drag coefficient changes because the integration for Z assumes c_d is constant.

A recent development is a QUICKIE formula giving the range X in a single step

$$\frac{X}{L} = \frac{\cos A}{2\,q\,c}\log_e\left(1 + \frac{4\,q\,C\,U_0^2}{gL}\sin A\right).$$

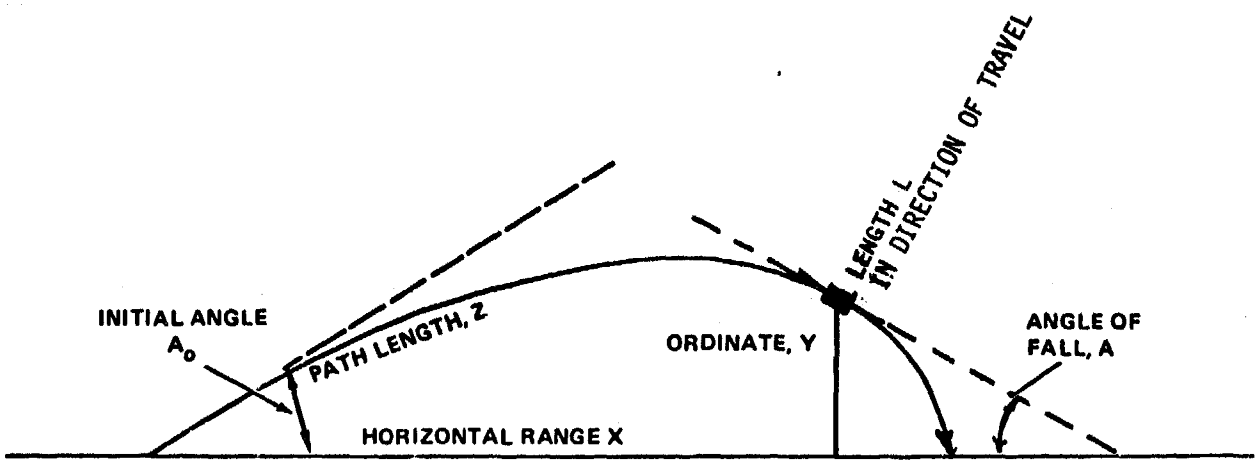
For small values of the argument, this becomes the classical trajectory in vacuo.
q = 1 for many low angle high speed trajectories with variable drag coefficients.
q is simply a device here to make the relation exact whenever needs be;
first solve for X(A) exactly with UNITRJ; then use QUICKIE to solve for q.
q is remarkably constant up to $A = 60^o$ and QUICKIE becomes a simple powerful tool:
a one-step expression with all the versatility that any analytic solution offers:
speed, variation of parameters, maximum range ($\frac{dX}{dA} = 0$), areal density (from $\frac{dA}{dX}$) etc.

Armed with FEN, UNITRJ, QUICKIE, or FRENCH, vistas of such problems become solvable. A few developments are indicated here, omitting the technical details.

Hazard factors (high vs low angle fragments) (See Figure 12)
For a given initial velocity, a fragment arrives at range X via a long or short path. The high angle fragments are usually spent by their long path, excepting a few so large, around 100 grams, that their terminal velocity alone makes them hazardous. Hence, all fragments above 100 grams would be unacceptable; high or low, H = 1. For small enough fragments, the energy will be spent by drag even via the short path. For intermediate masses, only the low angle fragments will prove hazardous. It was found with UNITRJ, but verifiable with any code, that for size L at range X the ratio of slow, high angle fragments to fast, low angles is around 10:1. In such cases, the hazard factor is about 10%, that being the chance it was low angle. Using QUICKIE, one can map out hazard factors in a few minutes that would require a month using a conventional differencing trajectory code (an actual comparison).

Second peak in areal density (far field threat)
Close-in, horizontal areal densities are low, due to flat trajectory; then rise and eventually the densities decline, due to X^{-2} divergence, and pulled down by gravity. Some investigators report a second peak in areal density, around 1800 feet. Our studies show it was a spurious result from analyzing a single fragment size. How? The derivative dX/dA measures the spread of fragments; at maximum range dX/dA=0. Hence it is clear that a code will give areal density dA/dX = ∞ at maximum range. As is easily verified by QUICKIE, nearly all fragments land near their maximum range. But by the same token, there are zero fragments of that exact size L. When we take into account any realistic distribution of fragment sizes, we find that the areal density decreases steadily, beyond the first maximum, and is well-fitted by exp(-constant X), the usual straight line on semi-log paper.

Rigidity of the trajectory
This is a well-established principle in artillery gunnery. It means that for small changes in angle of elevation A, the trajectory does not change shape. One can calculate concisely by algebraically adding ΔA to every trajectory angle. Example: the QUICKIE was derived using the principle of rigidity of the trajectory. Rigidity is a powerful tool, provided one knows the limits of it applicability. UNITRJ verified the principle quantitatively; showed it applies for $A<20^o$. This limitation is acceptable for NESIP; most hazardous fragments have low paths.

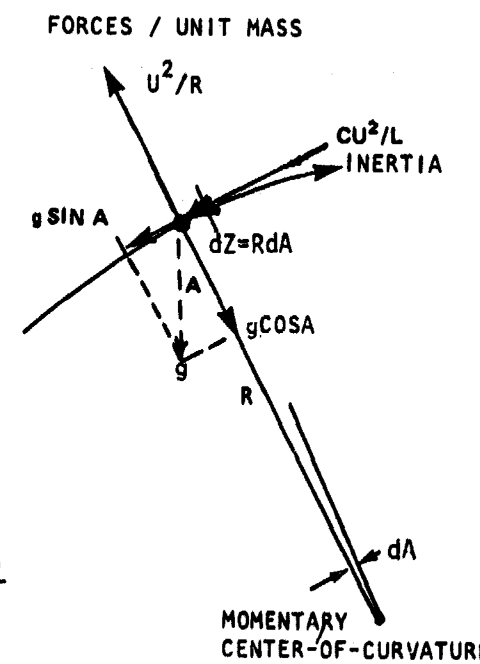


THE FORCE DIAGRAM IN COORDINATES Z, A AS SHOWN LEADS TO (EXACT) ANALYTIC RELATIONS FOR

$$\frac{e^{2CZ/L}dZ}{K} = \frac{-dA}{\cos^3 A}$$

$$\text{PATH } Z = \frac{L}{2C}\ \text{LOG}\left[1+\frac{KC}{L}\left[f(Ao) - f(A)\right]\right]$$

$$\text{VELOCITY } U = U_o\left[\frac{\cos Ao}{\cos A}\right] e^{-CZ/L}$$



WHERE

L = FRAGMENT LENGTH $\cong (M/BD)^{1/3}$

$$C = \frac{1/2 \cdot \text{DRAG COEFFICIENT}}{\text{SHAPE FACTOR}} \cdot \frac{\text{AIR DENSITY}}{\text{FRAG DENSITY}} = \frac{1}{2}\cdot\frac{Cd}{B}\ \frac{D_o}{D}$$

$$K = \frac{[\text{INITIAL VELOCITY} \cdot \cos(\text{INIT. ANGLE})]^2}{\text{GRAVITY}} = \frac{Uo^2\ \cos^2 Ao}{g}$$

$$f(A) = \frac{\tan A}{\cos A} + \text{LOG}\left[\tan A + \frac{1}{\cos A}\right]$$

Do Z IN INCREMENTS $Z_{i+1} - Z_i$ FOR DISCRETE DRAG COEFFICIENTS C_d (U)

RANGE	$dX = dZ \cdot \cos A$
ORDINATE	$dY = dZ \cdot \sin A$
TIME	$dT = dZ/U$

FIGURE 11 NOMENCLATURE AND DERIVED EQUATIONS FOR U^2 DRAG

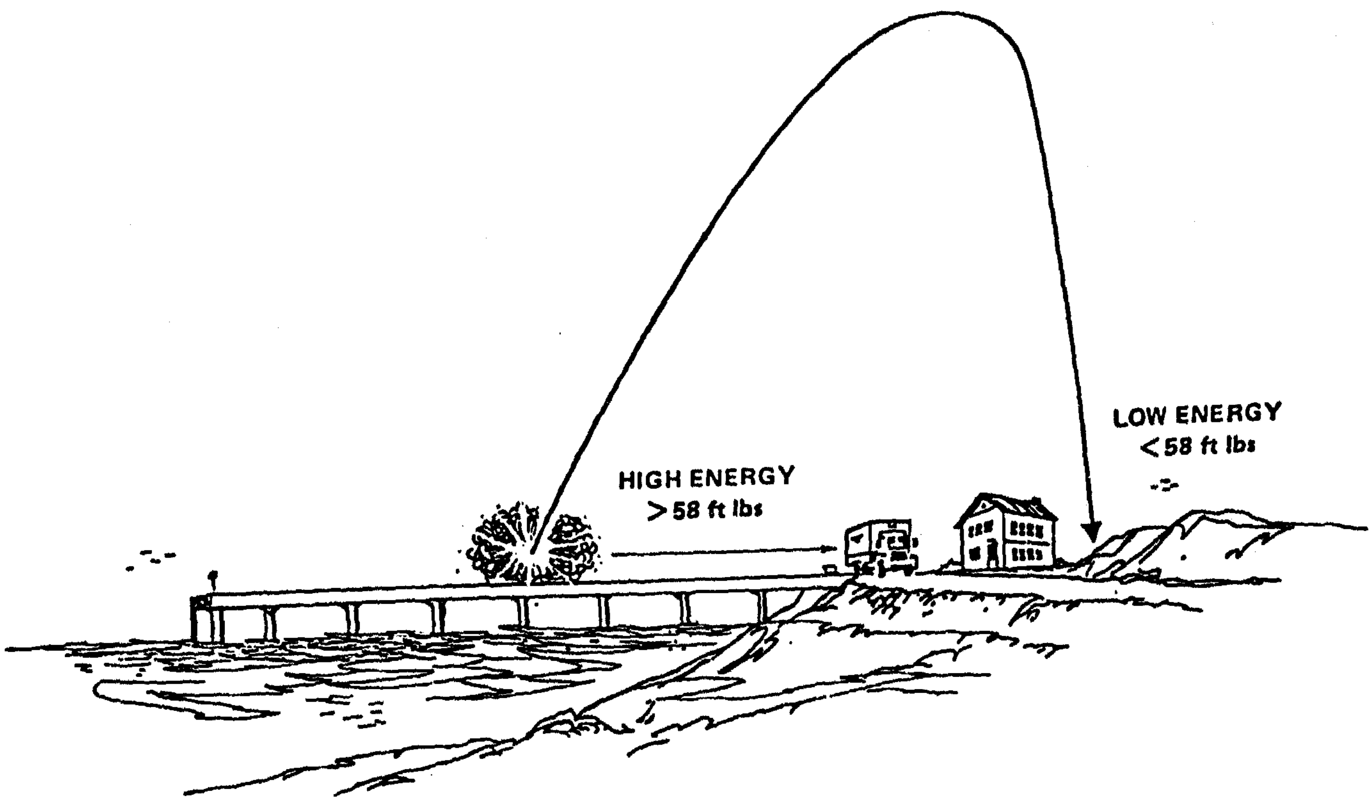


FIGURE 12. HIGH VS. LOW TRAJECTORIES

SYMPATHETIC REACTIONS

Details of the NESIP model and methods to control reactions were given in 1978.[17] Some highlights for these sympathetic reaction studies are summarized here.

Following UTE, most controlling effects can be embodied in an "action criterion": (See Figure 13).

$$\int (E(t) - E_c)\,d\tau > H_{minimum}$$

$(E - E_c)$ means that first the local energy density E must exceed some threshold E_c. The local energy E is itself a function of time and the net effect of two causes:

- o cumulative inputs: shock or impact, multiple hits, conduction, radiation, etc.
- o energy remaining after the natural flow of energy from any energized system,

Also, the molecules must be energized long enough for the atoms to move out from their lattice positions, disorganize, find new partners and reorganize as "explosive debris". In chemical terms one would say it takes time for the reaction to proceed! $\int E\,d\tau > 0$. The debris must have enough energy to energize its neighbors: sustain the chain. Blast decay, edge effects, size of incoming fragment may all limit the loading time. The shorter the loading time, the higher the initiating energy needs to be. But if the time is long enough, then E needs barely exceed the critical value E_c. By NESIP experience, the large scale gap test meets this requirement for long duration. Hence, H_{det} is implied by and estimated from the pressure and diameter of the LSGT.

In the SUSAN tests the sample is larger, a 3 inch diameter vs 4 cm for LSGT. The geometry is more complex and the SUSAN tests suggest another possibility: The minimum action H is probably not a single value, but a continuum from a threshold for burning, up through all degrees of deflagration up to detonation. Each represent a different exothermic chain; doubtless many chains are possible. Sometimes a chain dies out, but the definitive experimental fact: burning does sustain.

The action criterion embraces and is useful in correlating all sensitivity tests. Input pressure P or frag velocity U are intensive variables, directly related to E. Fragment diameter D and clearing times T are extensive, related through sound speed. From the action criterion, one can derive a special form for exposition here

$$U = U_c(1 + b/D)^{1/n}, \text{ where } U_c \text{ and } b \text{ are constants, and } 1<n<2.$$

For E~U, D small, then $U \sim D^{-1}$; Howe found that correlation for 105 shells, Comp B[18]. For $E \sim U^2$, $U = U_c(1 + B/D)^{1/2}$, much as Slade found $U = A + B/D^{1/2}$ for two explosives[19]. S. Jacobs extended that form with correction terms for other variables and L. Roslund uses it widely and successfully to correlate single fragment impact data[20]. For D large, as noted above, $U = U_c$ is the basic, classical idea in LSGT[21]. The action criterion most closely resembles the ρ^2T criterion,[22] but differs because E is cumulative modes of energy, is integrated, must exceed a threshold etc. Other effects are involved: history, porosity of HE, special geometry synergistics. All such forms apply in some domain, but clearly no specialized form applies to all. We are not dealing here with one "correct" mechanism, but with a class of reactions. The action criterion is a reminder of Nature's disregard of specialization and a discipline for bookkeeping all interactions that do occur in the real world.

Initiation is often controlled by the most sensitive components like RDX or HMX. An empirical plot of initiation pressure vs % sensitive explosive is useful. Figure 14 summarizes LSGT data with RDX as the sensitive explosive.

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[17] Porzel, F., "A Model and Methods for Control of Sympathetic Detonation," Minutes of the Eighteenth Explosives Safety Seminar, DoD Explosives Safety Board, San Antonio, TX, Sep 1978.

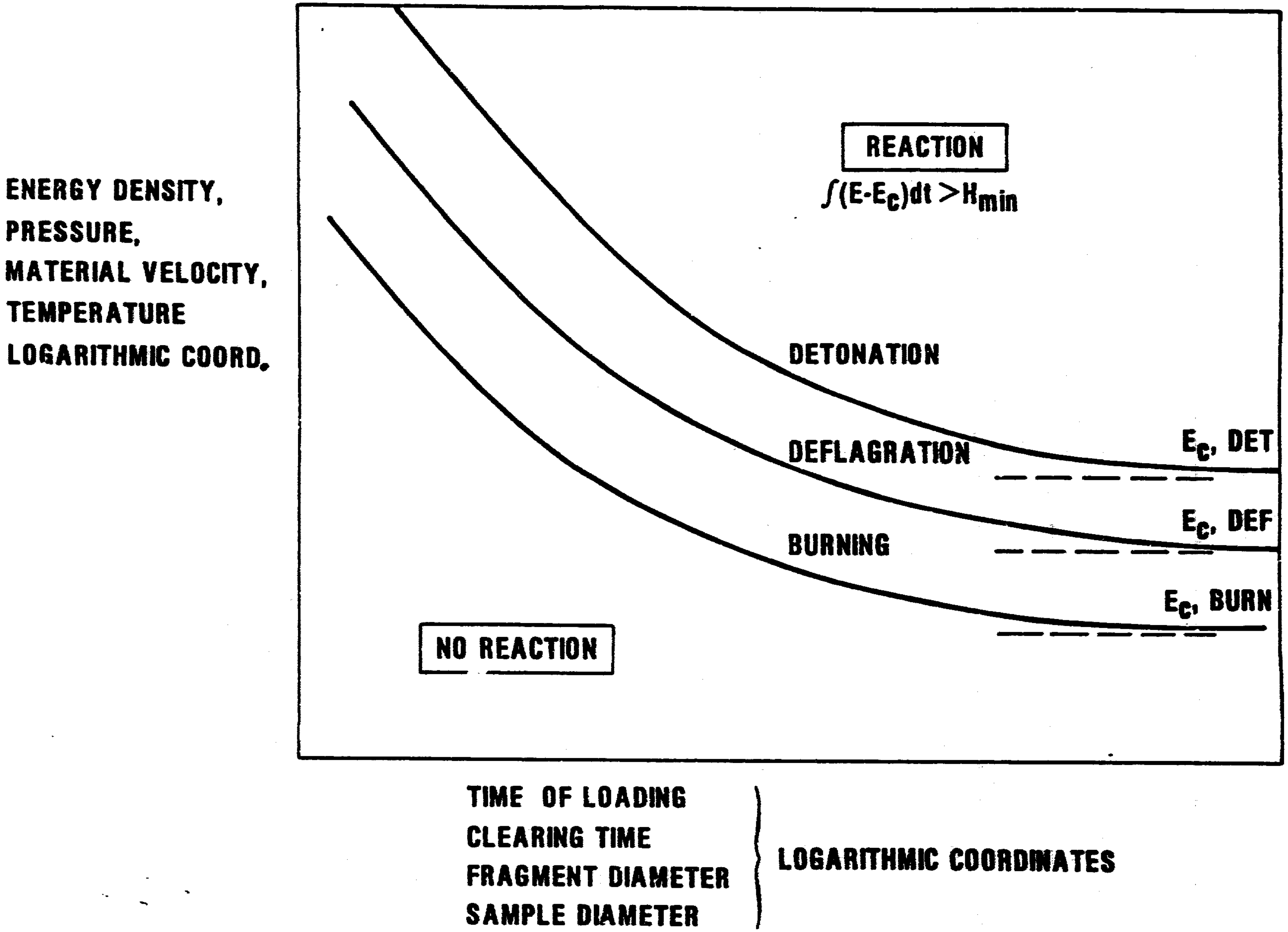


FIGURE 13 UTE-NESIP MODEL FOR SYMPATHETIC REACTIONS

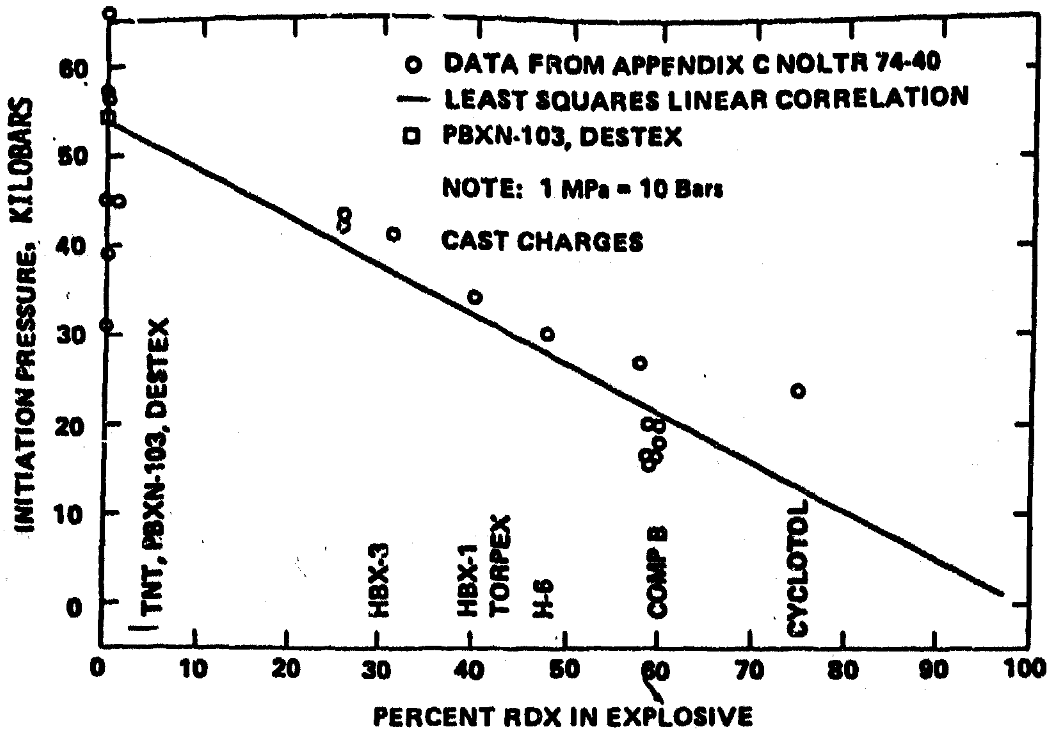


FIGURE 14a INITIATION PRESSURES FROM LARGE SCALE GAP TESTS
CAST CHARGES: RDX/TNT/INERT MATERIALS

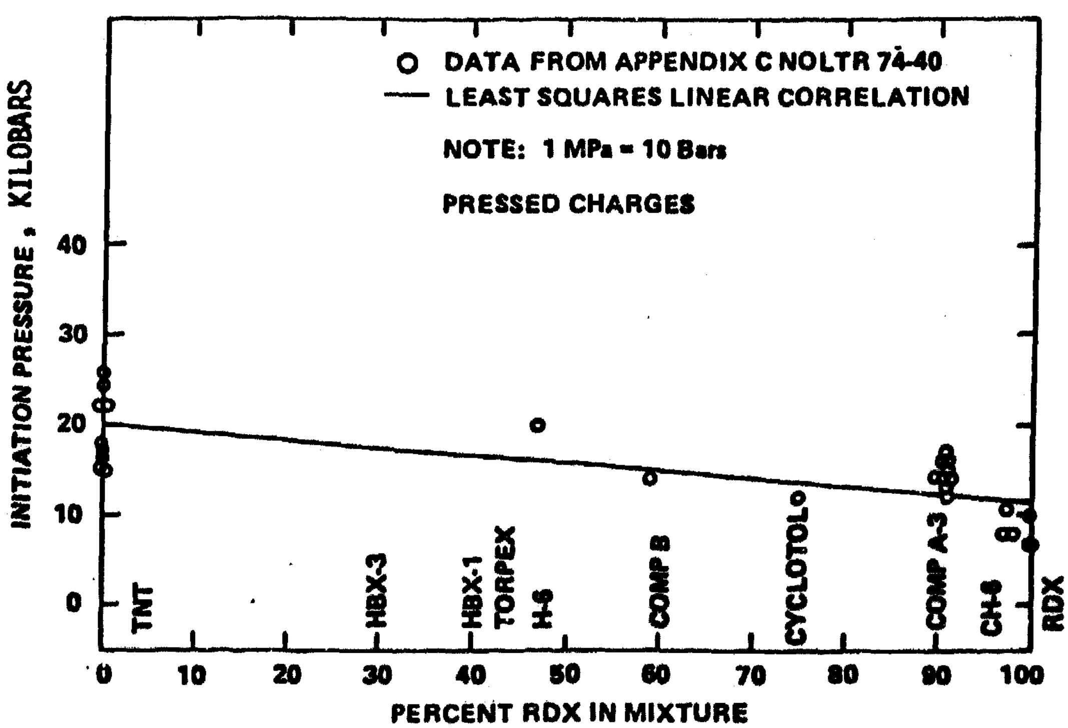


FIGURE 14b INITIATION PRESSURES FROM LARGE SCALE GAP TESTS
PRESSED CHARGES: RDX/TNT/INERT MATERIALS

While multiple hits do add synergistically, their effect also decays rapidly. A rule of thumb: they will not exceed twice the effect of a single fragment. For soft debris, the effect is about half the effect of a dense fragment. These rules are not needed if the local energy decay is actually calculated.

Given the input loading, say from UTE, and the pressure required for initiation, then the design of an inhibitor for sympathetic reactions is straightforward. A key idea and unique feature of the NESIP inhibitor concept is: we need not stop the incoming fragment, but only to slow it enough that its impact pressure is below the initiation pressure.

Figure 15 shows the design for a capsule to inhibit sympathetic detonation[17]. Note that the plates are only 3/8" thick, and 1½" wide, here for 5"/54 shells. It is important that the plates be thin enough to shatter and scatter so as to distribute their momentum as much as possible, otherwise they act together like a flyer plate.

The 1978 paper[17] reported a test that illustrates scattering and impedance (Fig. 16). Sympathetic detonation was prevented between Mk 16 torpedoes by a 5/16" plate. But when a 1/4" plate was faced on both sides with wood, detonation occurred. Evidently, the wood protected the steel plate well enough that it did not scatter but held together, struck the acceptor like a flyer plate, with full momentum. Here the impedance match between explosive debris and acceptor may be decisive. Steel (hard, dense) is a better inhibitor here than wood or plastic (light, soft). True, on the first impact the transmitted pressure is lower in the softer material. But, the velocity of the plastic is correspondingly higher and when the plastic impacts on the acceptor, the transmitted pressure is higher than if a steel plate had been used. Acoustic impedance D_oC_o in each material controls the physics.

To adequately limit the MCE, we need not confine the detonation to one donor. The fewer the acceptor detonations the better, but calculations often show that detonation of several acceptors will still be an acceptable MCE; and prove much less costly than complete inhibition. The chain either grows or not. If the probability of detonation is less than 1/(number of nearest neighbors) then the chain will probably die in a calculable number of steps.

Nose-to-tail stacking of torpedoes was conceived for three reasons: (Figure 17)

- o the tail section of an intervening torpedo is a ready-made shield
- o the distance between adjacent warheads is thereby longer
- o incidence is too glancing to permit sympathetic detonation, however close.

The idea in optimized storage is straightforward: use insensitive warheads as shields. If a warhead does not detonate under a specified blast load, it may be just as effective a blast shield or inhibitor as anything else that might be put in its place.

[18]Howe, Phillip, "The Phenomemology of Internal Communication and Techniques for Prevention," ARBRL TR 02048, U.S. Army Ballistics Research Laboratory, Aberdeen, MD, March 1978.

[19]Slade, D. C. and Dewey, J., "High Order Initiation of Two Military Explosives," BRL 1021, U.S. Army Ballistics Research Laboratory, Aberdeen, MD, Jul 1957.

[20]L. Roslund and S. Jacobs, private communications at NSWC.

[21]Price, D., "The NOL Large Scale Gap Test III. Compilation of Unclassified Data and Supplementary Information for Interpretation of Results," U.S. Naval Ordnance Laboratory, Mar 1974.

[22]Walker, F. E. and Wasley, R. J., Exposivstoffe, 17th, No. 1,9, (1969).

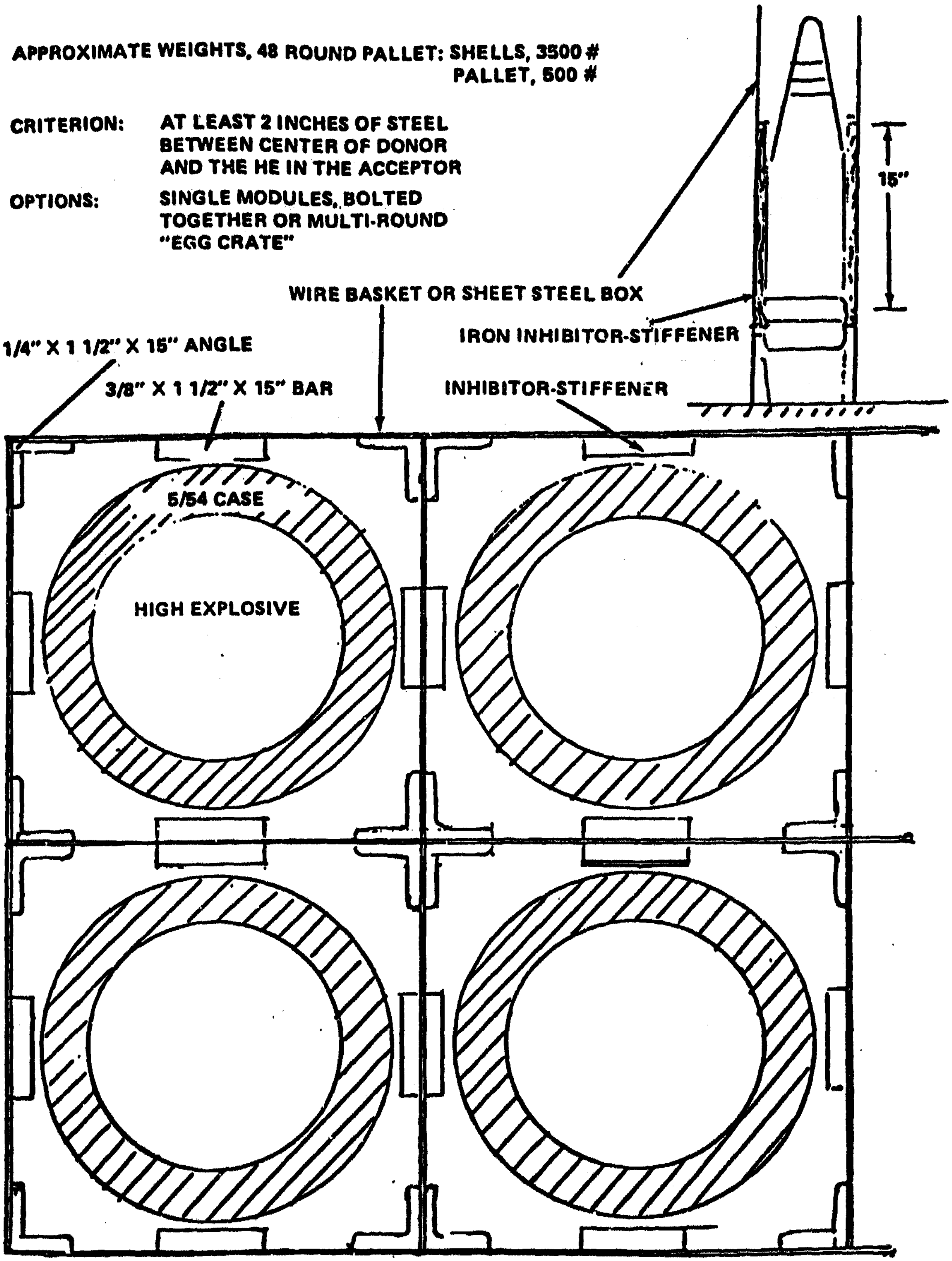


FIGURE 15. DESIGN FOR A MODULAR CONCEPT FOR AN INHIBITING PALLET FOR 5"/54 SHELLS TO PREVENT SYMPATHETIC DETONATION.

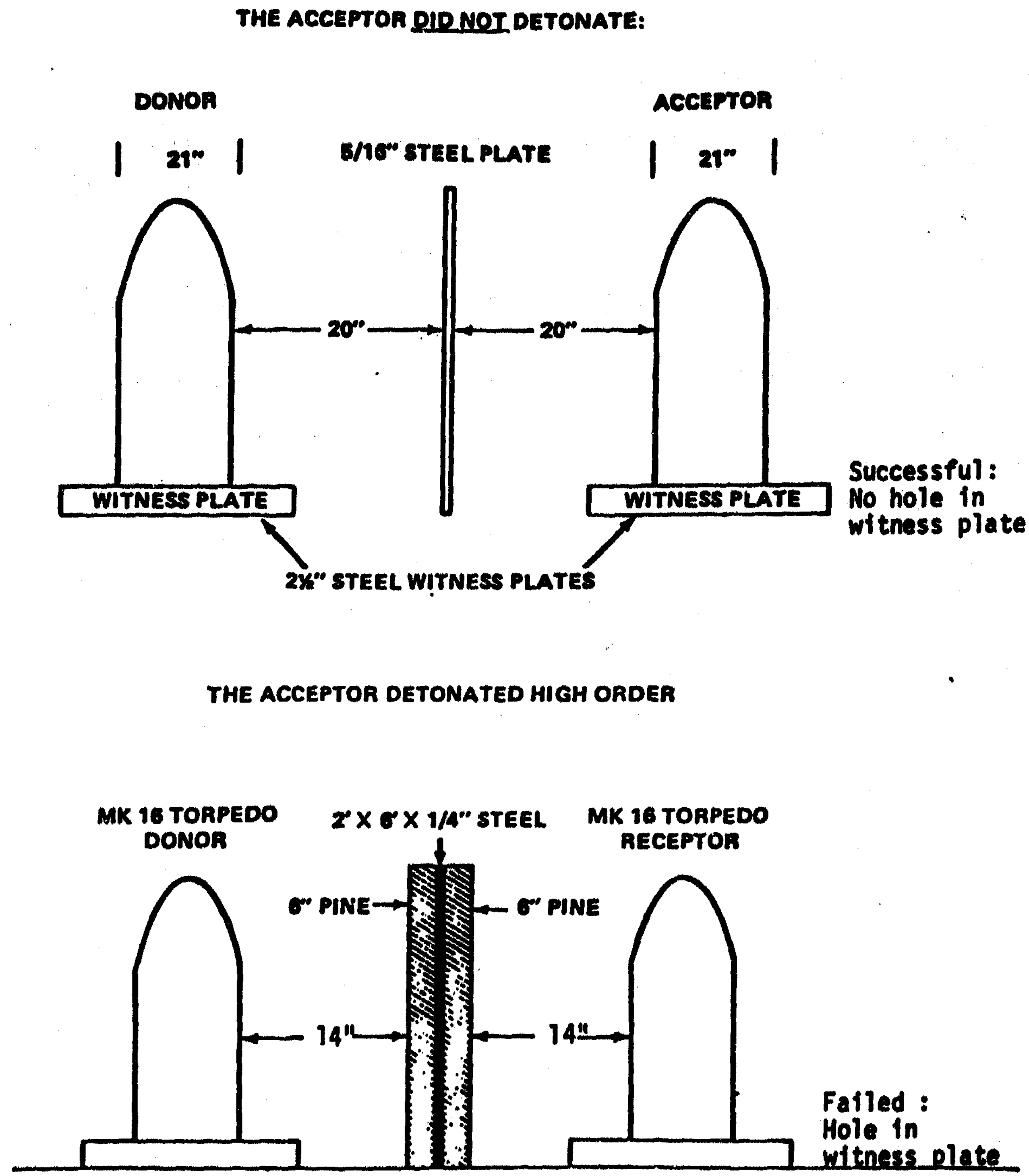


FIGURE 16. TEST OF STEEL INHIBITORS PLATE FOR MK 16 TORPEDOES WITH AND WITHOUT 6" WOOD FACING

NOSE-TO TAIL STOWAGE
WITH INHIBITOR PLATE OR BLOCK BETWEEN DIAGONALS

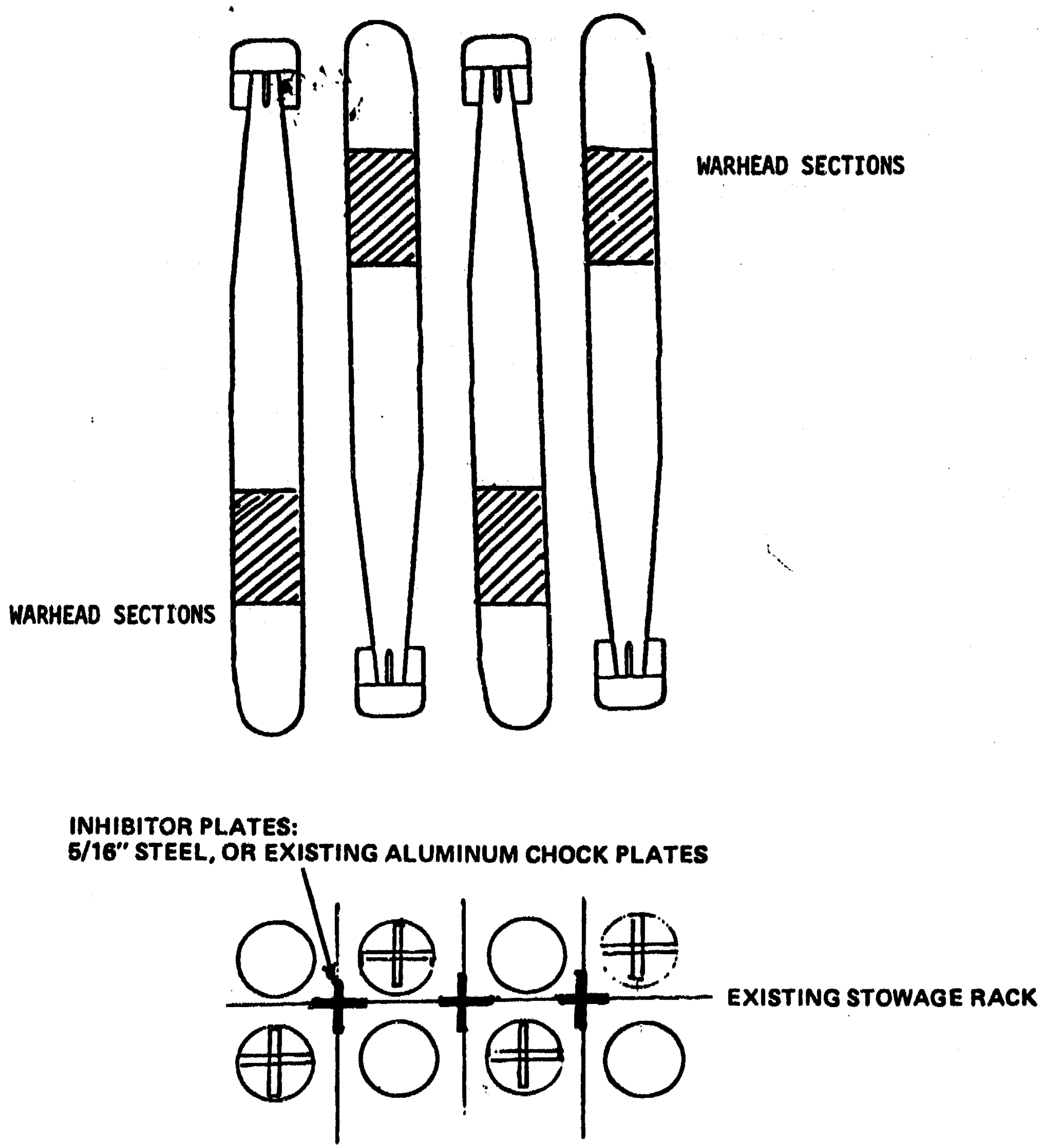


FIGURE 17. CONCEPT FOR NOSE-TO-TAIL STACKING OF TORPEDOES
Greater separation, mutual shielding, glancing incidence

EXPERIMENTS

These preceding techniques were applied and/or tested on about a dozen warheads.

- Torpedoes: Mk 16, Mk 46, Mk 48
- Missiles: TOMAHAWK, HARPOON, 2.75 inch rockets
- Projectiles: 5"/54 (Exp D and A-3), 5"/54 HIFRAG, 76mm fixed round
- Bombs: Mk 80 series, Mk 82 bombs in pallet

and a half dozen scenarios.

- Machrihanish (Scotland) Magazine
- New London Submarine Base
- Destroyer tender, Submarine Tender Workshop-magazine (AD/AS)
- FFG Magazine
- White Oak Sites
- General Ship-to-Shore problem

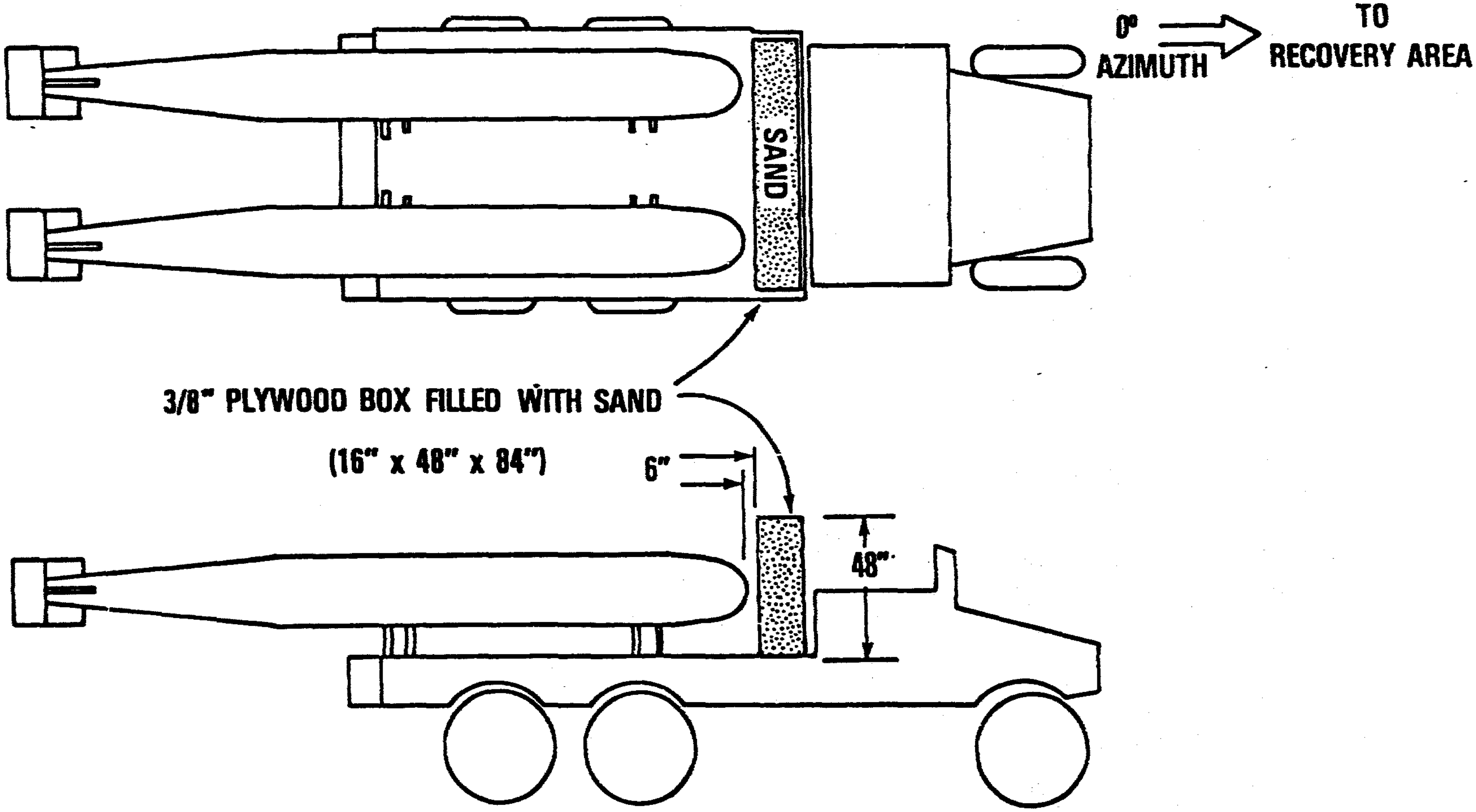
Controlling parameters for the warhead analyses are shown in parentheses; this is itself a result, because showing what is important is near the solution. Each different weapon often contributed to a new facet of the technology base more strongly than others; this is indicated by circles on the Table 1 and these highlights will be discussed for each warhead.

Mk 16 TORPEDO - (750 pounds HBX-3 in bronze case, 1/8 inch thick)
UTE analysis showed that two torpedoes deliver less than 1 psi blast at 500 feet. But the FEN charts showed the fragment hazard was unacceptable at 500 feet and a lightweight sand shield 1 foot thick was designed to reduce nose-spray. (Fig. 18) These analyses and shield design were summarized in the 1976 Safety Seminar[16]. The first two shots in the NESIP program, Sep 1975, verified the shield concept. As a result, the DDESB approved a reduction of the hazard arc from 1250 to 500 feet, with a savings in Navy construction costs estimated by CNO as $400 million.

Analyses and test for shielding against sympathetic detonation were given in 1978[17]. Initiation by a single fragment was expected and verified out to 32 feet, no shield. But a 5/16 inch steel plate with 40 inch separation prevented detonation (Fig. 16). That is also the deck thickness between workshop and magazine below it. Hence the existing ship structure and spacing can prevent propagation of reactions and specifically, detonation from workshop to a magazine below.

FIGURE 18

MINIMAL BLAST AND FRAGMENT SHIELD



Mk 46 TORPEDO - (100 pounds PBXN-103 or 105 in aluminum case .145" thick) Fig. 19 shows the reflected pressure vs distance as calculated using UTE. With no space between warheads, blast pressure calculates close to detonation pressure. Beyond 28 cm distance, blast pressures become too weak to initiated detonation, but the local pressure from impact of fragments can do so out to several However, calculations show that a ¼ inch steel plate placed midway between them or the two aluminum chock plates in the existing storage racks would work.

Mr. Martin will describe the tests in a later paper[23]. Briefly, the results were: At 24 cm distance, plates or not, the blast should have initiated detonation and did; at 36 and 56 cm distance the plates should have prevented detonation and did; at 74 cm, without plates, the fragments should have initiated detonation and did.

In open air, the donor was ignited to burn; the plates did shield the acceptor. But when the donor-acceptor pair were placed in a small cavity, the acceptor burned and mildly deflagrated, but significantly, did not detonate. This is a hohlraum effect, -- radiation reflected from walls of a cavity. To date, the open air and small box gives us a bracket on sympathetic burning but it remains to show which better simulates the space in a shipboard magazine.

Mk 48 TORPEDO - (PBXN-103 or PBXN-105 in aluminum case 1/4 inch thick) The same 5/16" deck plate that worked so well in inhibiting the Mk 16 torpedo[17] and the steel or aluminum plates that worked so well in inhibiting the Mk 46,[23] should work here to prevent propagation between decks and within magazines.

Because the Mk 48 is effectively twice the size of the Mk 46, to a first approximation we should retain the plate thickness but double the spacing. It worked. Dr. Connor will later describe some AD/AS workshop-magazine tests[24], which confirm the utility of thin deck plates to limit the threat to burning.

The plastic bonded explosive PBXN-105 is a replacement for the present PBXN-103. Analysis suggests 105 is less sensitive because of unusually low initial yield. A full magazine may not detonate, but this prognostication has not yet been tested.

[23] Martin, G. H., "The Explosives Hazard Presented by the Torpedo Magazine of a Guided Missile Fragate (FFG Series) During Pier-side Topping-Off Operations," 19th DDESB Seminar, Los Angeles, CA, Sep 1980.

[24] Connor, J. G., "Hazards from Accidental Explosions in Submarine Tender Workshops," Minutes of the Nineteenth Explosives Safety Seminar, DoD Explosives Safety Board, Sep 1980.

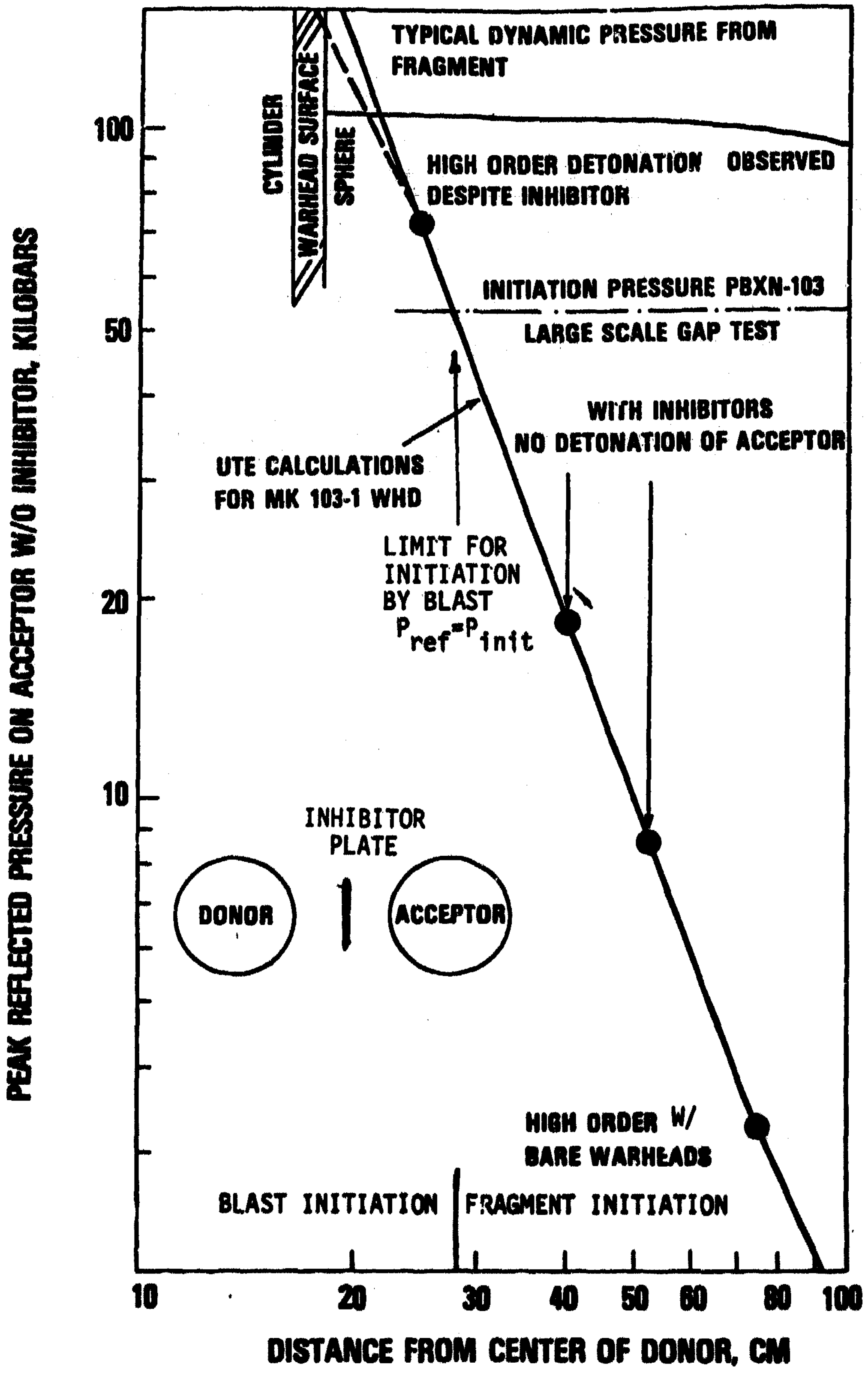


FIGURE 19. TEST PREDICTIONS AND RESULTS FOR INHIBITING SYMPATHETIC DETONATION BETWEEN MK 46 TORPEDOES (MK 103 MOD 1 WHD)

TOMAHAWK MISSILE - (168 Kg HE mostly H-6, in 254 kg steel case ⅛ inch thick, 59 kg aluminum airframe, 138 kg solid propellant; total missile weight 693 kg) Dr. Ward reported on the analyses and tests of this missile in 1978[25]. The project was a comprehensive check-out and verified blast predictions with UTE, fragment predictions with FEN charts and features of trajectory analyses. Both blast and fragments proved acceptable hazards at 500 feet without change.

Besides verifying techniques, some novel ideas which have broad application are:

- Immediate surrounds. Only the material close-to and enclosing all the HE receives enough energy and is broken into enough fragments to become a hazard. Hydrodynamic venting drastically relieves the blast pressure on the rest. For example, the propellant tank remained intact during the explosion and was found about 50 feet from its original location in the missile.
- High versus low paths. As previously discussed, many more fragments arrive via a high angle trajectory than via a nearly flat, high speed trajectory. Only the largest fragments, above 100 grams, weigh enough, are large enough that their terminal energy exceeds 58 foot-pounds.

HARPOON MISSILE - (97.5 kg DESTEX with 133.8 kg steel airframe-warhead case, 392 kg overall weight)

Analysis showed both blast and fragments were acceptable at 500 feet w/o change. In view of the excellent agreement between TOMAHAWK predictions and tests, it was not deemed necessary to verify the HARPOON predictions with tests[25].

2.75 INCH ROCKET - (5 lbs Comp B in 26" long case, L/D ≅ 10, 5.9 lbs N5 propellant) The problem: how much does the propellant contribute to the air blast? Navy directives give a blanket rule: count propellants as 25% equivalent weight. Recent tests were made of air blast from single rounds, 25 and 49 round stacks. Based on scaling, the equivalent weight of propellant was said to be "at least 100%".

However, NESIP analyses using UTE showed that classical scaling does not apply. Pressures are relatively high close-in, but are an assymmetry of blast due to the long cylindrical charge; the effect dies out by 1 psi.
With UTE, the contribution from the propellant was found to increase the blast energy:

Single rounds	0%
25 round stack	24% per round
49 round stack	37% per round

A general implication here for all warheads: while propellants do burn rapidly, they are a "delayed energy" in UTE terms, resembling afterburning. They burn too slowly to contribute more than a minor fraction of their energy to the blast at low pressures; their energy is trapped behind the negative phase. The general agreement around 25% among afterburning in HE, earlier Navy experience, and these tests suggests the limiting fact is formation of the negative phase. It does not depend strongly on the kind and quantity of propellant or explosive. 25% appears to be a valid rule of thumb for many different applications.

[25] Ward, J. M., "Simulated Tomahawk Missile Handling Arc Test Results," Minutes of the Eighteenth Explosives Safety Seminar, p. 1527, DoD Explosives Safety Board, San Antonio, TX, Sep 1978.

5"/54 PROJECTILE - (7.8 lbs Exp. D or Comp. A-3 in a 70 pound steel case, .65 in thick)

Details for both fragmentation and sympathetic detonation were given in 1978[17]. For Exp. D fills, sympathetic detonation did not occur, even at zero spacing. With Comp A-3, the distance for 50% probability of detonation, $P_d(50)$, varied repeatedly on different tests from 6 to 12 inches, depending on lot. But the standard pallet of 48 shells (6x8 array) has spacings of 1" and 2", so there is no question, and tests verify, that the pallet will mass detonate. Fig. 15 was a design concept, verified by test, to stop sympathetic detonation by placing a steel plate 3/4" thick, 1½" wide and 15" long between rounds[26].

The action criterion suggests that duration of stress counts as much as intensity; the mere fact of a P_d is sufficient evidence that divergence controls the duration. A plane wave acts locally as if duration were infinite.
Hence, a 3/4" plate placed between quarter pallets (a 3x4 array) of shells should not prevent sympathetic detonation (by theory) and did not do so (by test).

5"/54 HIFRAG PROJECTILE - (6.5 lbs PBXN-106 in a 58.6 lbs steel case, 0.8" thick)

We found that blast and fragments appear to be acceptable hazards beyond 500 feet based on UTE for blast, FEN charts for fragments and a few $P_d(50)$ tests[27].

Despite the name HIFRAG, our analysis shows the fragment size distribution is not sensibly different from the standard 5"/54 round. However, the HIFRAG is less hazardous than the standard round for several novel reasons:

1. PBXN-106 requires twice the initiation pressure of A-3: 25 vs 12 kilobars,
2. has half the detonation pressures: 100 kilobars vs over 200 for A-3.

At the closer (1") pallet spacing, the probability of detonation was 0.6.
At the larger (2") pallet spacing the probability of detonation was zero.
Thus the chances are a full pallet may not mass detonate, one row would, whereas the standard round A-3 pallet did so completely.

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[26] Patent pending, F. B. Porzel.

[27] Ltr Ser: 8010, CO NSWC to CO NAVSEASYSCOM, 5 Aug 1980, Subj: MCE for HIFRAG Projectile.

<u>76 mm FIXED ROUND</u> - (1.3 lbs A-3, 10.6 lbs steel case, brass cartridge, 5.4 lbs M-6 propellant)

A lively interest arises here because the gun is set atop the FFG. Just below is the gun turret and 76 mm magazine, below that a Mk 46 torpedo magazine. Mr. Martin will give a subsequent paper describing the experiments[23].

The 76 mm (3") projectile is like a 3/5 scale replica of the 5"/54 with A-3. If fragment velocity were the criterion, one would expect a $P_d(50) \approx 6$ inches, which is larger than the 2" spacing between rounds in the turret stacks. The HE weighs 1/6 as much, 1.3 lbs vs 7.8 in the 5"/54, and noting $1/6^{1/3} = .55$, if $Y^{1/3}$ scaling applied, the predicted $P_d(50)$ would be $6 \times .55 = 3.3$ inches. Either way, they mass detonate. One imagines an accident in the gun turret leading to mass detonation of its magazine and then the torpedo magazine. But following the action criterion of the technology base, loading time is reduced both by the shorter pulse duration of the explosive and by the faster time for unloading the stress because of the smaller case. Scaling for action suggests a $P_d(50)$ spacing like 1.3 in., verified by experiment. The probability of sympathetic detonation is nil at 2 inches. Thus there is no chance of sympathetic detonation in the turret ring and even less in the stacks, where the round is stored in a shipping container.

In a test of extreme confinement, a 4x4x4 foot box - vs the whole magazine, a few of the closest cartridge cases were perforated and propellant burned. Analysis shows the fire was equivalent to burning a half gallon of fuel oil -- a problem with which the ship's crew can easily cope.

Mk 80 SERIES BOMBS - (typically 40% HE, 60% steel case, 3/8" to 1" thick)

Early in the NESIP program, excellent correlation was found between arena data and the UTE formulations for size distribution, average size and velocity of fragments such as $N(>L) = N_0 \exp(-L/\overline{L})$ and $\overline{L} \approx \frac{1}{4}$ case thickness. Nowadays, agreement with these data for a single bomb of the series is not really a new finding, but to be expected from the earlier NESIP research.

In using data, since one has no control over bomb orientation at explosion time, the NESIP approach emphasizes the average values for polar angle and velocity as more realistic than to use the worst polar sector as typical (5° out of 180°), or to use the fastest particle from an arena data panel (1 fragment vs thousands).

Mk 82 BOMBS IN PALLETS - (Six rounds, each 200 lbs HE in 300 lbs steel case, .62" thick).

Dr. Ward will present a subsequent paper on the analysis and tests of pallets[28].

Note now that according to standard practice in calculating air blast, a heavy bomb case, energy loss to ground and the long cylindrical shape all strongly reduce the air blast: Fano factor, reflection factor, etc. Fragments would probably be regarded as the controlling hazard at 500 feet. Yet two remarkable results, consistent with the UTE-NESIP technology base are found.

1. None of the "corrections" apply, neither Fano, ground shock, nor L/D. The UTE predictions are based on spherical symmetry for mass effect of the case with no correction for energy losses by the case or to the ground.

2. Blast, extending to about 600 feet, is the controlling hazard, not the areal density of fragments as measured on a horizontal surface. Areal densities normal to the trajectory are largest of any plane but the criterion is customarily applied to ground area.

An important implication and a powerful analytic tool is seen here: The energy release from such warheads can be evaluated from near ground air blast just like free air spherical charges of the same explosive of twice the yield. This has been the practice for single bombs near ground for a decade using UTE. Note, in Dr. Ward's paper, how precisely the idea applies to pallet data. (Heretofore, the standard practice would call for a reflection factor--not known--and/or height-of-burst correction, in addition to case correction, L/D etc.)

[28] Ward, J. M., "Blast/Fragment Hazards Associated with Accidental Explosion of a Mk 82 Bomb Pallet," Minutes of the Nineteenth Explosive Safety Seminar, DoD Explosives Board, Sep 1980.

SCENARIOS AND SITES

The preceding analyses and tests were applied to 6 sites and scenarios so far:
- Machrihanish (Scotland) Magazine; a spectrum of all Navy Weapons
- New London Submarine Base; hazard from explosion of an SSN magazine
- Destroyer Tender, Submarine Tender Workshop-Magazine propagation (AD/AS)
- FFG Magazine, 76 mm gun turret, magazine and Mk 46 magazine
- White Oak Sites
- General Ship-to-Shore Problem.

These studies usually require a broad application of the technology base. Often they were characterized by a specific warhead which is shown in parentheses.

MACHRIHANISH (SCOTLAND) MAGAZINE - (Spectrum of thin-skinned Navy weapons)

These studies[29,30] provide comprehensive prototype analyses of a magazine adjoining others that store thin-skinned weapons vulnerable to massive debris. The problem: an explosion in one might propagate like a chain across the site. The analyses include UTE blast predictions for a massive magazine explosion, simplified structural analyses, correlation of sensitivity data for many explosives and experiments for impact of brick debris on such warheads. The warheads analyzed include: torpedoes, Mk 46 and 48; Mines Mk 52, 53, 54, 55; CAPTOR; HARPOON; QUICKSTRIKE, Ex 62, 63, 64, 65 and Destructors. None of these were found vulnerable to an explosion in the adjoining magazine. Of general interest are: the correlation of explosive data, brick rubble tests and safety measures for magazines that might contain vulnerable explosives.

NEW LONDON SUBMARINE BASE - (Full magazine, Mk 48 torpedoes in attack submarine)

The problem: What are the hazard arcs assuming detonation of the full magazine?

Guided by analyses, a comprehensive set of scale model tests showed that the hazard arc is less than 200 feet for both blast and fragments. Because: a submarine is an ideal pressure vessel for containing blast and fragments and the crowded internal equipment is an excellent absorber for blast energy. Since the loading is far too low to fracture the hull, or rupture it violently, fragments are constrained to speeds of the whole fore and aft section of the hull. This is because the explosion does not vent out the top of the hull; if it did, the internal equipment would be a major hazard.

Mr. Swisdak will describe the experiments in detail. Note in his paper[31] the role of hull and internal equipment in reducing both blast and fragments, and the evidence of the innocuous failure mechanism we here call "break and tear."

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[29] Porzel, F., and Ward, J., "Safety Analyses of the Machrihanish Magazine," NSWC WOL TR 79-359, Naval Surface Weapons Center, White Oak Laboratory, 1979.

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WORKSHOP - MAGAZINE ON A DESTROYER OR SUBMARINE TENDER (AD/AS)

The problem here is the propagation of an explosion in a torpedo workshop to the torpedoes stored in a magazine directly beneath the workshop. Dr. Connor will give a subsequent paper on the experimental results[32].

The Mk 16 tests of inhibitors described earlier were a prototype for this program. Again it was found that the existing 5/16" steel deck plate of the workshop was sufficient to prevent sympathetic detonation of the torpedoes below. The magazine warheads and propellants in the magazine did burn, not violently, and would not be a blast or fragment hazard to shore installations 500 feet away.

GUN VERSUS TORPEDO MAGAZINE, MISSILE FRIGATE FFG - (76 mm gun, Mk 46 torpedo)

Recall the 76mm gun and magazine are on a top deck, the torpedo magazine below. The major concern: a 76 mm accident propagating to the torpedo magazine. Mr. Martin will describe this problem and tests in detail[23].

The FFG illustrates how data are correlated with the technology base; and how the solution is clear once the intermediate steps are known. The 76mm is like a 3/5 scale model of the 5"/54, which characteristics were known[17]. The sensitivity of the Mk 46 torpedo with PBXN-103 was known from Machrihanish[9]. The stopping power of absorbers was tested and reported in the 1978 seminar[32]. The use of thin plates as inhibitors for torpedo was verified in the Mk 16[17]. It is a straightforward extension to put these ideas together for the FFG.

The .25" aluminum deck plate now between magazines limits the threat to burning. The addition of a ¼" steel plate below the deck virtually precludes burning. A ½ inch steel plate, in a few strategic places, will preclude penetration by the 76 mm fragments entirely.

A new aspect of technology on this study was radiation effects in confined spaces. With donor-acceptors in the open, the chock plates prevent sympathetic burning. But so confined a space as a 4 foot cube is a hohlraum, or radiation cavity. Now both acceptor and donor will deflagrate via radiation flooding the cavity. Significantly, neither donor nor acceptor detonated, despite the confinement. The main reason here is the action criterion for sympathetic detonation. Radiant energy via the walls is delivered too slowly ever to raise the local stress on the acceptor up to and over the critical stress level E_c. The acceptor will react by burning rather than detonating.

[32] Connor, J., "Shields for Decelerating Munitions Fragments," Minutes of the Eighteenth Explosive Safety Seminar, P. 1769, DoD Explosives Safety Board, San Antonio, TX, Sep 1978.

WHITE OAK SITES

Everyone has to comply with the DDESB safety criteria; including our own sites. Most of our structures were easy applications of the NESIP technology base.

A new feature arose here, that is easily overlooked in paper studies. A firing site is treated in theory as flat-as-a-pancake and perfectly open. Yet, when you look at an actual site, you see a host of natural barriers: hills, berms, buildings, dense stands of trees; all attenuate blast and fragments. The same must often be true: crowded piers, buildings, walls, trucks, etc. But you have to get out of the office and look at the actual site to appreciate that these natural barriers even exist!

SHIP-TO-SHORE GEOMETRY

This is a good place to recall our initial problem, our approach, and barriers:

- o Problem: the hazard to the shore from an explosion at the pier
- o Approach: make maximum use of what we already know (or ought to know)
- o Observation: natural barriers are often overlooked.

What is the angle of elevation for a lethal fragment to land at 500 feet?
By $U = Z/T$ a typical high speed fragment at 5000 f/s gets there in .1 sec.
Then $Y = \frac{1}{2} gT^2$ is sufficient to tell us it drops only .16 ft, or 2 inches.
The angle of elevation is $\tan^{-1}$ (.16/500') = .02 degrees
Thus, the fragments that count are virtually line-of-sight! (Fig. 12).

Now it is not much of an assumption that the shore is above sea level. The only direction a hazardous fragment can reach land is up-hill (Fig. 20) A large fragment going up-hill at 5000 f/s or so, will land near 2000 feet. It is impossible to land such a fragment closer on a horizontal plane ten feet high. At 9000 f/s, a 20 gm fragment that just clears the cres, lands near 1000 feet. In other words, the shore itself is a natural barrier to high speed fragments. Vertical targets are vulnerable, but are shielded by any block to line-of-sight. Fragments small enough to have curved trajectories are non-hazardous when they hit. Larger fragments, hazardous at impact, are too disperse by the time they land. Very massive high angle fragments , 100+ gm, exceed 58 ft lbs by terminal speed, but such fragments are only a small fraction of the total: $N = N_0 \exp(-L/\Sigma)$.

True, most piers are above sea-level; a sniper can shoot a warhead lofted by a crane. Yet it would be simply stupid to let a saboteur stop us from seeking safety as we can. The essential point in seashore shielding is that the profile is concave downward somewhere, and we ought to exploit that fact whenever it is useful.
That brings us to the end of the paper.
If we need protection, cannot find it in shields, inhibitors, prudent stacking etc. perhaps we can seek safety successfully by seeing some shielding by the sea-shore.

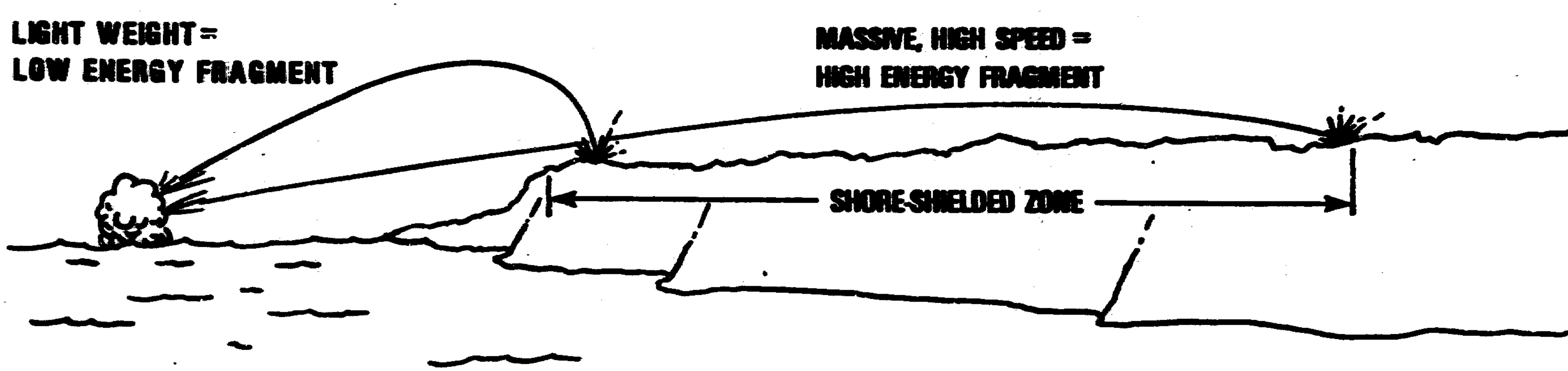

FIGURE 20 SHIELDING BY THE SEA SHORE

SUMMARY

NESIP offers an organized set of novel methods, codes and formulae to

- o solve any explosion safety problem -- as best one can with data at hand
- o explain and correlate existing data -- among many specialized fields
- o predict new weapons effects and scenarios -- as needs may arise.

These methods were applied and tested over a broad spectrum of Navy weapons that includes torpedoes, missiles, bombs, shells -- on piers, in ships and magazines.

All current Navy weapons analyzed and tested so far were found either acceptable hazards near 500 feet without change or could readily be made so by

- o minimal shields -- against blast and fragments, or
- o minimal inhibitors -- against sympathetic detonation and burning, or
- o prudent variations in stacking and storage, or
- o minimal barricades -- exploiting natural terrain and cover.

ACKNOWLEDGEMENTS

I had lots of help, (and you can too!) from:

- o John Connelly of OP41, and Edward Daugherty of NAVSEA Safety Office, 04H3 who posed the problems, steered the program and above all, risked money on it.
- o Joe Petes, longtime program manager of NESIP at White Oak, Mike Swisdak, the present manager, Gruver Martin, the Test Coordinator, Jerry Ward, Joe Connor, Don Smith, Phil Aronson, Dave Compton, the NESIP team who conduct the projects and bear the burden of implementing all this.
- o Phil McLain, and all the TERA staff at New Mexico Tech for most able direction and splendid copperation on the field tests.
- o Les Roslund, of NSWC White Oak, always a most willing and capable guide through the history and pitfalls of sympathetic detonation.

I name last the two men who were in fact the first:

- o Captain D. Knudsen USN, now deceased, the Founding Father of all the NESIPrograms. He set the original goals and directives. He was "the guy who made the wheels go."
- o Dolf Amster, early NAVSEA director of NESIP., now at NWC, China Lake an early and forthright champion of UTE when it needed help the most: He was its first SPONSOR! Can one say more in government reasearch?

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MISSILE HAZARD FROM EXPLOSIONS IN SHIPS

by

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INTRODUCTION

This paper presents a method proposed for use in the Navy Explosives Safety Improvement Program (NESIP) to predict the missile hazard resulting from accidental explosions within ships. The NESIP objectives supported by this work are to define the unsafe zone around an explosion of concern, and to define design criteria for protection of facilities within the zone.

In conformity with reference (1), a hazardous missile is defined as one impacting with at least 58 ft-pounds (78.6J) of kinetic energy, and the unsafe zone is defined as any region in which one or more hazardous missiles hit per 600 square feet ($55.7m^2$). The intention of these criteria is apparently that the risk of serious injury to unprotected persons engaged in typical activities be quite low*. Reference (1) distinguishes categories of land use requiring application of the criteria so as to protect people in open fields and in buildings of varying height. Reference (1) does not require such analysis for sites more than 1250 ft (381 meters) from the potential explosion, based on review and analysis of a great number and variety of explosion events by the Department of Defense Explosive Safety Board (DDESB). Because of the high value of real estate surrounding areas where the U.S. Navy would like to operate ships with some degree of explosive hazard, it is desirable to define the unsafe zone and the protection required to make the zone safe, at ranges less than 1250 ft (381 meters). It appears that a minimum range of around 500 ft (152 meters) is a realistic goal for establishing or providing site safety.

*Since analyses are performed using the "maximum credible event" (defined in reference (1)) which greatly overstates the average potential event, and since explosive events are infrequent, the actual risk is as low as many risks routinely accepted by adult humans.

For example, the great preponderance of missiles ejected by the 1977 SANSININA explosion in Los Angeles Harbor appear to have landed within that range, though missiles of ship or ship munition origin have been known to fly many miles.

The development of a model for analyzing the missile hazard due to explosions within ships is motivated by the large number of ship classes of interest in the NESIP.

MODEL

APPROACH

Direct analysis of the missile hazard from explosions within ships is complicated by the extensive jobs of identifying potential missiles and their individual propensities for separation from attachments, defining the time-dependent loading within the multiply-venting irregular structure typical of ships, predicting the response of the structure to create apertures for missiles from within and to propel external contiguous objects, and calculating missile propulsion by gasses expanding from the irregularly opening ship structure. Therefore, our approach to modeling is to hypothesize that ships and explosions originating within them behave in similar fashion, and use data from actual explosions to characterize that behavior.

OVERVIEW OF MODEL

The proposed model predicts a volume of ship interior which can donate missiles, apertures through or from which missiles can emanate, and sections of deck or side which attain high speed even though they don't open fully

to form apertures. It then predicts statistics on number, drag retardation parameter, speed, and angular dispersion of missiles, all broken down by missile mass category. These predictions are based on data derived from movie and still photographic records and accompanying accounts of several ship explosions, as discussed later. The model then samples from the distributions defined by the predicted statistics so that the missiles are individually defined in terms of the exterior ballistics problem. The model then solves the exterior ballistics problem for each missile and determines which 25 foot sectors of range and altitude of potential targets intercept each missile trajectory. The sectors are the line segments of a grid ranging from 475 ft to 1275 ft in range and from 25 feet below the center of the explosion to 200 ft above the explosion center. For each missile a permanent record is kept of its mass, its initial velocity vector, its calculated translational speed, momentum, and kinetic energy, and its trajectory angle at each pierced grid sector. Given a list of the grid sectors which represent a particular target, the model then goes through the record of each missile to determine whether it hit the target, and, if so, with what kinetic energy. It then tabulates the hit counts, subdivided according to range of impact energy. These hit counts are then divided by the ratio by which the number of simulated missiles exceeded the number actually expected at the 90% confidence level. The results are next multiplied by factors to assure that azimuthal dispersion is taken into account and that each grid sector represents 600 square feet of target area. The model can then find the level of low cut-off of impact kinetic energy at which the average or highest hit count per 600 square feet does not exceed unity.

This level provides a basis for approximating the degree of missile protection needed to meet the DOD safety requirement. Further sorting of the stored records can then be made using protection parameters involving obliquity, speed, etc., to support more explicity critieria for protection design and demonstration testing.

A similar process is proposed for analyzing the threat from very large missiles, many of which act as described in Reference 2: (Referring to the second explosion aboard CORINTHOS)

> "The trajectory of this huge section of the CORINTHOS cargo tanktop was described as floating up in the air and out towards the EDGAR M. QUEENY in a 'slow motion' fashion... observed... with binoculars... at a distance of approximately 3 miles."
>
> Another example of such missiles is described in Reference 3 involving 600 tons of explosives. The bridge and midship section of the exploding ship landed on another ship 200 to 250 yards away. A "large portion of stern" came to rest on a ship directly astern.

It is clear that few such missiles can be expected even in the worst case, and that potential very large missiles can be readily identified on the basis of the initial analysis of ship structural response. Many of those potential missiles cannot be expected to fully seperate from Navy ships as has been repeatedly demonstrated not only in tests involving at most a few hundred pounds of TNT equivalent, but also in the case of the U.S.S. SOLAR explosion which involved roughly 10,000 pounds of TNT equivalent. Present Navy ships generally have significantly more resistance to formation of large (completely separated) fragments than have ships such as those discussed above.* Based on our review of Navy ship response to

*Riveted structural panels of some decommissioned Navy ships have more readily failed due to interior explosion, following a trend seen in merchant ships. The latter are often further weakened in resisting internal blast because of their many large compartments, i.e. larger panels.

actual internal explosions, it is conservative to assume that only half of the potential huge missiles expected in NESIP analysis can be expected to fly.

Massive missiles are devastating at impact, and much larger than the size conceived of in the derivation of the 600 square foot impact zone criterion. In particular, they are bigger than a person. An analogous specific area requirement for one of them would be about 10 times the maximum projected area of the missile.* For a typical massive missile, this would indicate a specific area requirement an order of magnitude larger than 600 square feet. Thus, considering both of the above factors, it is proposed to multiply the predicted number of identifiable potential large missiles by half the ratio by which they exceed six square feet, in order to get missile counts relatable to the 600 square foot criterion.

INPUT

The proposed model requires prescription of:

(1) The amount of explosive involved. This is expressed in pounds of TNT, with TNT equivalence of explosives based on heat of combustion.

*As discussed in reference 4, "The probability P of a strike by one or more fragments is calculated from formulas of the form:

$$P = 1 - \exp(-qA)$$

where q is the fragment density (sic. number of fragments per impact area) and A is the exposed vulnerable area of the individual." A value of 6.2 square feet for A is also ascribed to reference 5, so that the value of the exponent at one hit per 600 square feet is about -0.1. The formula applies to the case of missiles small with respect to the target (i.e., to 6.2 square feet). Massive missiles from ships can reach 600 square feet in presented area. The strike of one such missile in a 6,000 square foot target area would then give a value of -0.1 for the exponent in the above equation, where P would be interpreted in the same way, i.e., the probability that a human within the 6,000 square foot area is struck.

(2) Fragmentation characteristics of individual munitions which could be considered to explode after the ship structure has been opened by a preceeding explosion.

(3) The ship arrangement, including compartment free volumes, possible missile barriers, the location in the ship of the explosive at issue, and an assessment that the usage of individual ship spaces is such that the per-volume number of potential dense missiles* is (a) not greater than the numbers available in the test ships used in this study, or (b) increases the test ship numbers by definite factors.

(4) Ship structural capability to contain an explosion, in terms of materials, primary structural dimensions, and special features which enhance venting (e.g., construction which effectively provides blow-out plugs) or increase containment (e.g., liquid backing or heavy objects).

DEVELOPMENT OF MODEL ALGORITHMS AND DATA BASE

The prediction of ship structural failure causing loss of internal boundaries and opening of weather plating is accomplished using blast damage modeling recently developed by Hill at the David W. Taylor Naval Ship R&D Center (DTNSRDC) for the purpose of ship vulnerability assessments. That modeling is based on appropriate test data, and its predictions compare well with general war damage experience. Since relatively high precision is required of blast response modeling here, detailed comparison of predicted vs. actual failure of individual ship structural panels was carried out. Some averaged results for eight ship explosions

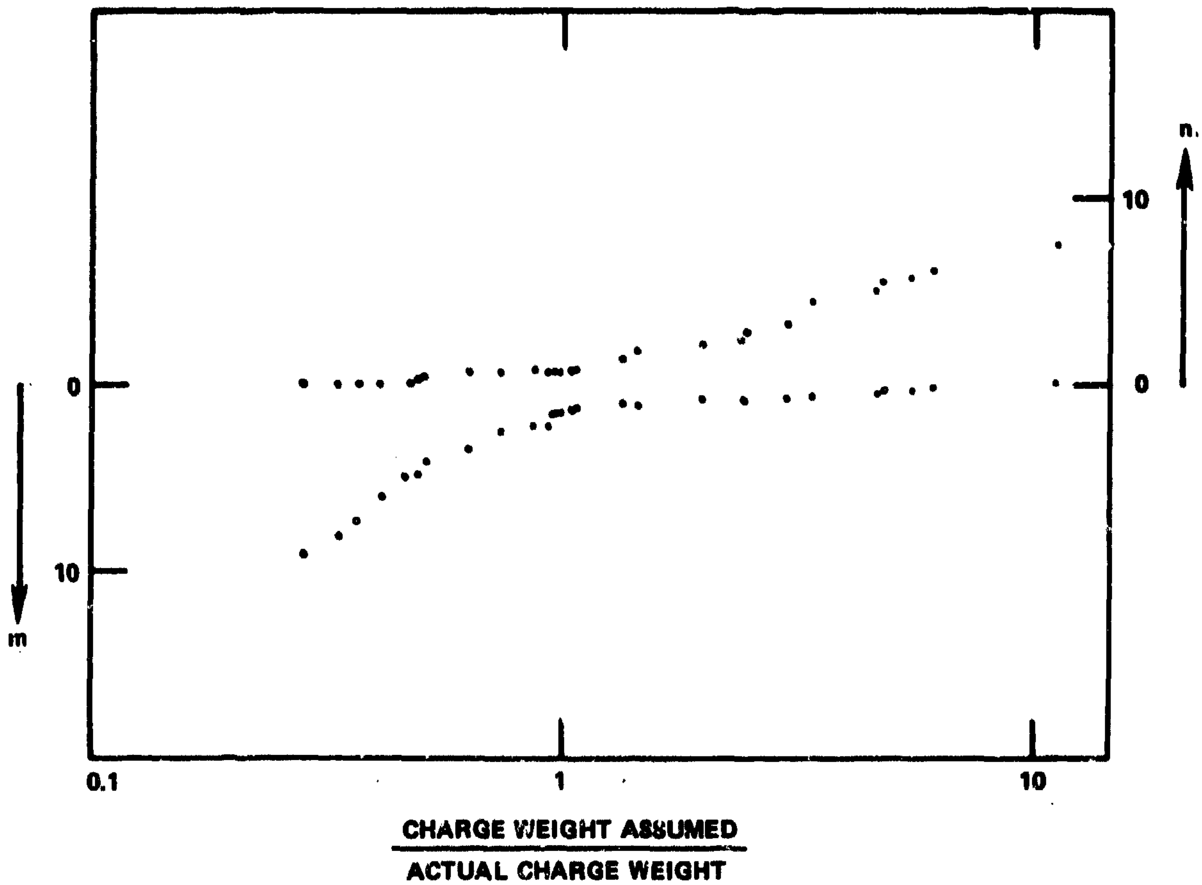
*i.e., items which are unattached or which would tend to be detached by shock or blast loading, such as pipe fittings, hatch covers, unexploded rounds, handling equipment, fire extinguishers, and pieces of ship structure.

are shown in Figure 1. In the upper part of the figure is plotted the average number n, of upright panels* predicted failed but not actually failed, while the average number, m, of upright panels not predicted failed but actually failed is plotted in the lower part of the figure. The abscissa of figure 1 is the ratio of charge weight assumed for prediction by the model divided by the actual charge weight. It can be seen that the model is reasonably well calibrated with respect to the charge weight. A few alternative models were assessed in like fashion but found not to improve precision.

Figure 2 shows results for the same eight tests, which were conducted at the same location in ships having nearly identical structure, and for a test conducted in a ship of very similar design. The significant difference in designs was that in the former, an additional small compartment was located within a large compartment at the center of the ship. The charges were exploded inside the small compartment.

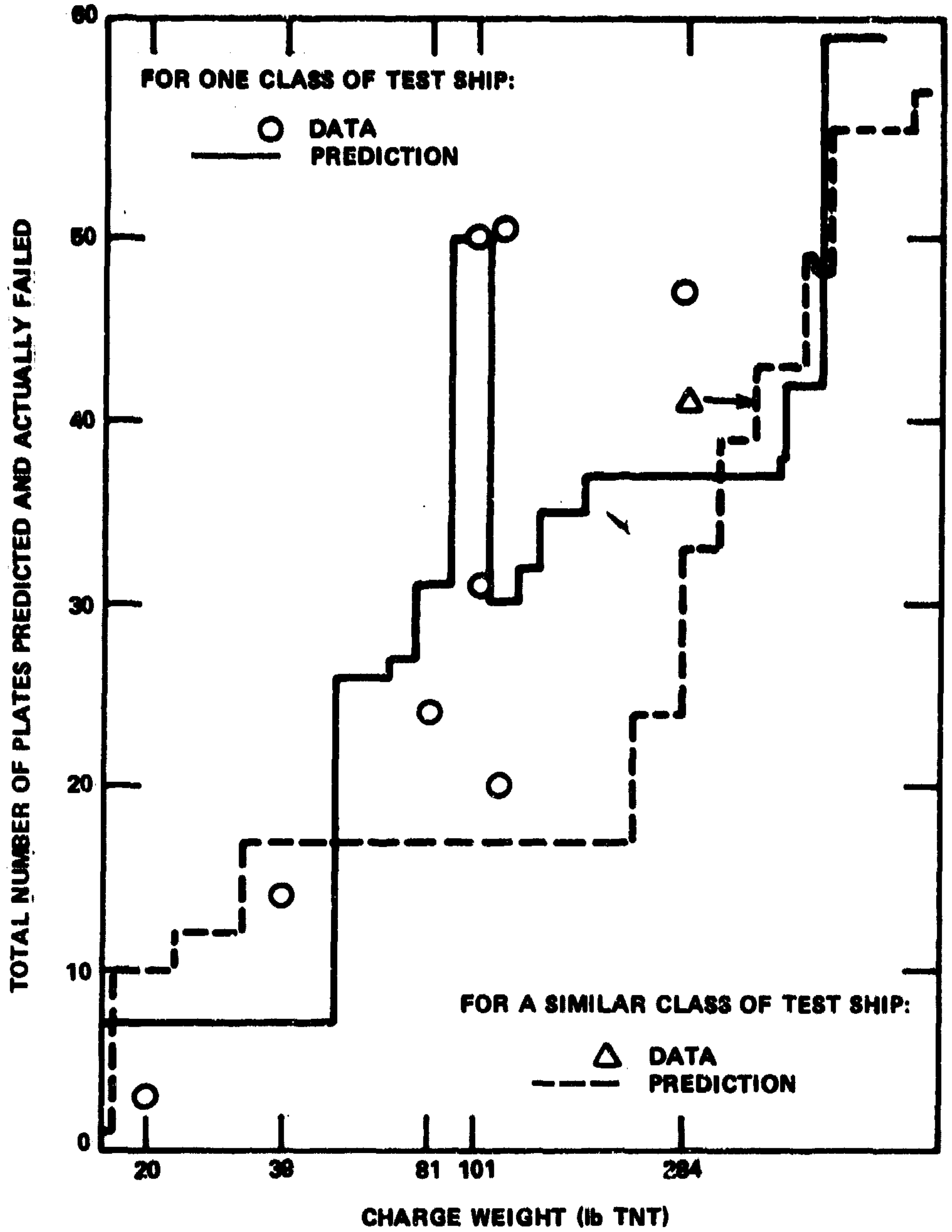
The predicted total number of panels failed does not increase monotonically with charge weight for either design, nor did it do so for other tests. The reason is that over a range of charge weight, venting is predicted to reduce the load on some plates below their failure threshold. These ranges provide an opportunity to test the model's capability to handle the complex interaction between loading of various parts of the structure and venting. There is a suggestion in Figure 2 that such a range actually occurs, and roughly as predicted. Figure 2 also shows the sensitivity of prediction to structural variation. As would be

*To facilatate comparison of alternative models, deck panels were not included in figure (1).



n = NUMBER OF PLATES PREDICTED FAILED BUT NOT ACTUALLY FAILED (AVERAGE).
m = NUMBER OF PLATES ACTUALLY FAILED BUT NOT PREDICTED FAILED (AVERAGE).

Figure 1



60
50
40
30
20
10
0
TOTAL NUMBER OF PLATES PREDICTED AND ACTUALLY FAILED
FOR ONE CLASS OF TEST SHIP:
DATA
PREDICTION
FOR A SIMILAR CLASS OF TEST SHIP:
DATA
PREDICTION
20
38
81
101
284
CHARGE WEIGHT (lb TNT)

Figure 2

expected, the greatest difference in prediction between these two particular designs is for "small" charge weights, below about 250 pounds of TNT here.

A prediction of the number of panels destroyed aboard the U.S.S. Solar was approximately 10 percent higher than the number estimated to have been destroyed. Thus the method appears to be appropriate for the larger charge weights anticipated for NESIP study.

The model's characterization of missiles is based on analysis of the motion picture and still photographs, and on test reports, of thirteen test explosions. The tests were conducted in welded steel hulls, and they represent four variations of ship structural arrangement surrounding the charge. These surroundings had fixtures and equipment typical of the spaces to be analyzed for NESIP except for racks of projectiles, some of which could become missiles in an accidental explosion. The surroundings had a variation of up to about 4:1 in volume of containment before massive venting. There was a similar degree of variation of effective charge weight.

Much light debris which floated much slower than dense missiles was seen, but not counted. Even in the high energy explosion of the SANSINENA, such debris piled up quite close to the ship. To detect possible differences in missile characteristics according to missile size, missile counts were made in four size categories. These categories correspond roughly to mass ranges as follows:

up to .28 pounds (.127 kg)
.28 to 2.8 pounds (1.27 kg)
2.8 to 28 pounds (12.7 kg)
28 pounds and up

Preliminary calculations indicated that the smallest category would generally fail to meet the impact energy criterion, except when projected nearly horizontally from a position above target altitude. Missiles in the smallest category were estimated to be below the threshold of visability, and splashes from "invisable" missiles were counted in that category. The measured initial speeds within the smallest mass category were found to be significantly greater than the speeds of other missiles when the small missiles were ejected during the very earliest stages of opening of exterior ship panels. Trajectories of these faster, small missiles did not exceed an angular separation of about 30 degrees from the plane of holes which opened in a surface of small curvature. The effective nozzle orientation early in the process of hull opening lay in the middle of this small sector, as determined by disturbance of the water. Therefore, it is assumed that fast, small missiles have comparable dispersion for nozzles however oriented, including nozzles formed at corners such as the intersection of a side with the main deck (these missiles could not be observed in the movies). We could predict the orientation of "corner" nozzles according to the ratio of dynamic compliances of the intersecting panels, but would then have to make assumptions about the loading also. Preliminary calculations indicate that only within a fairly narrow* band of elevation angle of missile initial velocity vector should the small, fast missiles be expected to impact beyond a 500 foot range with 58 foot-pounds of kinetic energy. Therefore, it is not deemed overly conservative to apply the numerical density of small, fast missiles, derived for a 15

*i.e., not more than about 30 degrees at speeds corresponding to much greater explosive charges.

degree dispersion, to all possible angles of elevation. For upright corners, it seems appropriate to do likewise, except that the range of azimuth should not exceed 90 degrees.

Dispersion of larger missiles was found to be uniform over sectors related to apertures in the ship. The missile count per steradian* was at least an order of magnitude greater within those sectors than outside them.

Four types of dispersion were observeable in the available movies:

(1) side-on view of ship. Main deck and sides opened as shown schematically in Figure 3.

(2) view from port quarter of ship. 01 Level overhead provided the only significant external hole facing upward. Essentially all missiles seen rising above the ship were in directions from the center of explosion through that hole. See Figure 4.

(3) fore-aft view of an explosion like those represented by figure 3. This is shown schematically in figure 5. Other views of this explosion confirmed that the missile density was uniform in all directions permitted by the remaining ship structure and virtually all the missiles flew out within the limits indicated in Figures 3 and 5.

(4) side-on view of ship. The aft end of the superstructure was hinged up to an approximately vertical plane as shown in figure 6, and the missiles flying above the ship were seen to be uniformly distributed within the directions passing from the charge center through the hole thus formed.

Estimates of dispersion out of the plane of the viewing screen were required. For some of the tests, there were film records along roughly perpendicular directions (e.g.,broadside and nearly dead ahead). For tests in which only one general viewing orientation was available, out-of-plane dispersion was estimated with the aid of wideangle coverage which showed some

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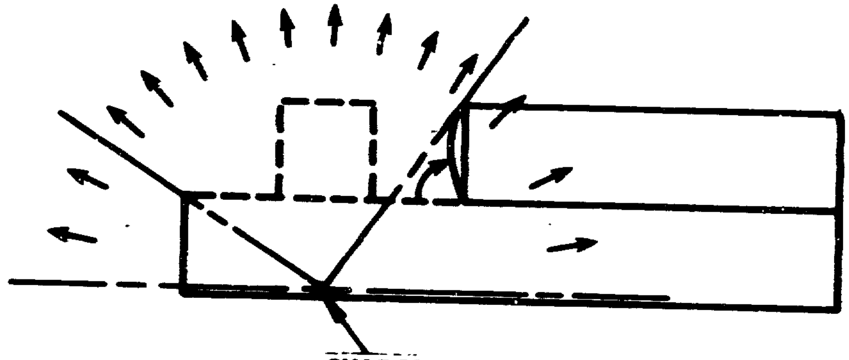
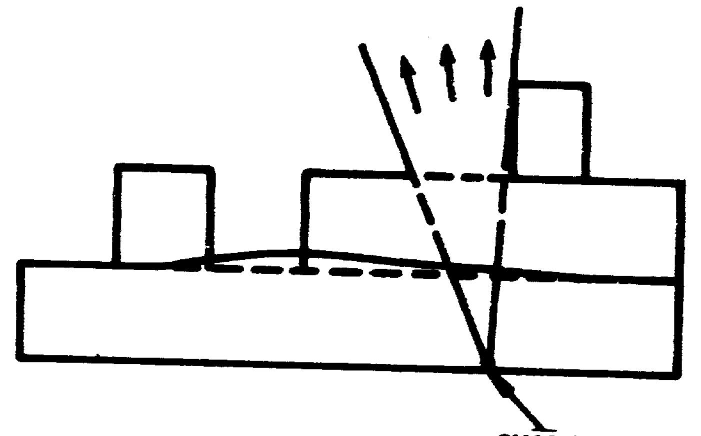
* Angles measured with apex at the center of the charge.



EXTREME SECTORS OCCURRED WHEN SIDES OPENED ALSO

Figure 3



INTERIOR DECKS HOLED

Figure 4

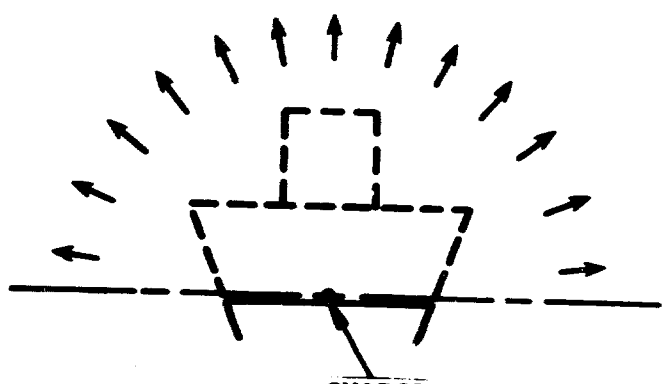
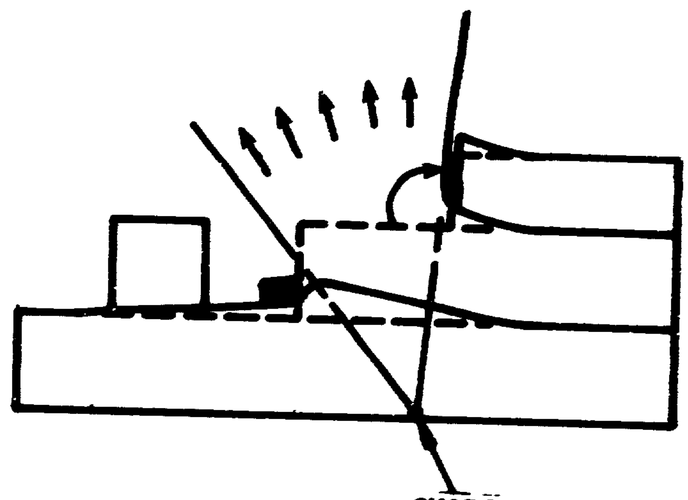


Figure 5



INTERIOR OF MAIN DECK HOLED.

Figure 6

splashes and some wide, long-range, splashless zones. Such coverage also seemed to improve perspective. Comparison with other test observations was also used to estimate out-of-plane dispersion. The missiles were taken as uniformly distributed over their out-of-plane sectors.

It is concluded that "slow" missiles should be modeled as uniformly distributed, over sectors in azimuth and elevation subtended at the center of the charge by the holes.

Missile counts were divided by the volume swept out within the ship by their solid angle sectors. The statistics on number of missiles per volume of ship origin are given below.

smallest group:	N = 0.195	S = 0.115
	N = 0.130	S = 0.160
	N = 0.201	S = 0.207
largest group:	N = 0.055	S = 0.045

N is the estimated mean and S is the estimated standard deviation of the number of missiles per cubic foot of ship volume. When weights are ascribed to the groups as mentioned above, the mean weight of missiles in pounts per cubic foot of ship (about 11) agrees well with the ratio of dry displacement to ship volume (roughly estimated to be between 10 and 12-1/2 pounds per cubic foot) of the test ships.

Missile shape, size, and attitude with respect to trajectory were noted, along with whether the missile was tumbling or not. The missiles are assumed to be made of steel, based on ship description, and it is planned to calculate their drag retardation coefficients so as to define the population of coeficients (by missile size group if coefficient distinction is significant at a 70% confidence level).

Missile speed distributions are plotted in Figure 7. These plots suggest that the three large size categories of missiles have initial

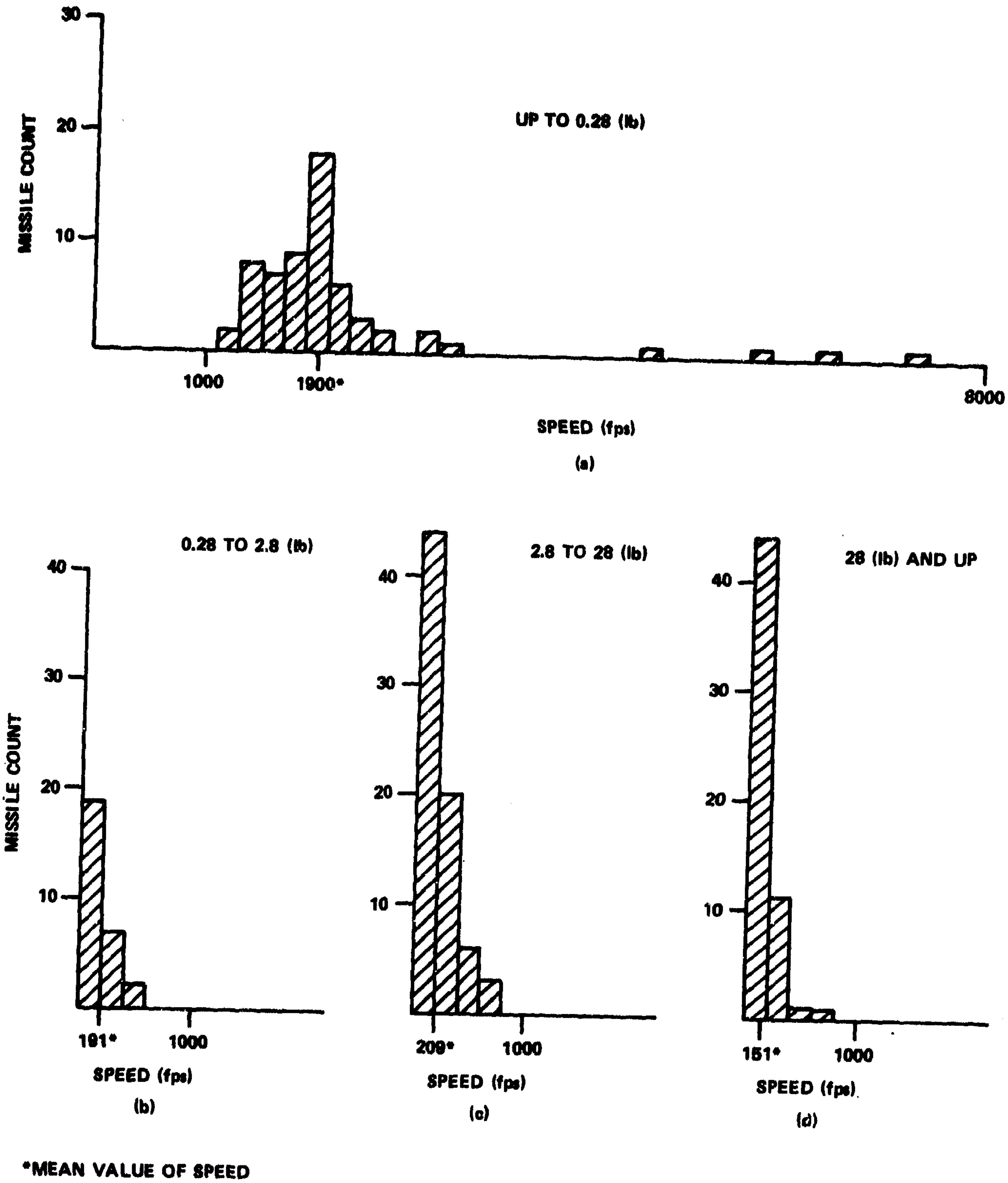

UP TO 0.28 (lb)
MISSILE COUNT
30
20
10
1000
1900*
8000
SPEED (fps)
(a)
0.28 TO 2.8 (lb)
40
30
20
10
191*
1000
SPEED (fps)
(b)
2.8 TO 28 (lb)
209*
1000
SPEED (fps)
(c)
28 (lb) AND UP
151*
1000
SPEED (fps)
(d)
*MEAN VALUE OF SPEED

Figure 7

speeds which may fit exponential distributions (decreasing speed with increasing mass). The small fast catagory of missile has initial speeds which may fit a normal distribution.

It is to be expected that missile speeds increase up to some limit with charge weight and vary inversely with volume of containment and degree of venting of the explosion. Indeed, Figure 8 shows that missile maximum range tends to increase with charge weight. The figure represents data mostly compiled by Dr. Ilsley formerly of DDESB. The data are taken from accounts of many types of explosions including ship incidents, and suggest a dependence of range on charge weight to some power in the region of 1/2 to 1/3.

We propose to extrapolate from the missile speed statistics found in this study on the basis of the adiabatic work potential*, W_p of the blast overpressure** and volume in the burst compartment being partitioned in the same proportions as in the data we have extracted. Thus our proposal is to predict missile speed statistics according to the trend of our data. Over the limited range of values of W_p in the tests we analyzed, the average missile speed, v, appears to vary according to the equation $v^2 = .0005\ (W_p - 60 \times 10^6)$, where v is measured in feet/second and W_p is in foot-pounds.

PLANS

The remaining statistics to be used in the model are being calculated and will be available soon. The first application of the model will be for the purpose of validation.

*for expansion to atmospheric pressure
**as predicted by the previously discussed DTNSRDC blast modeling

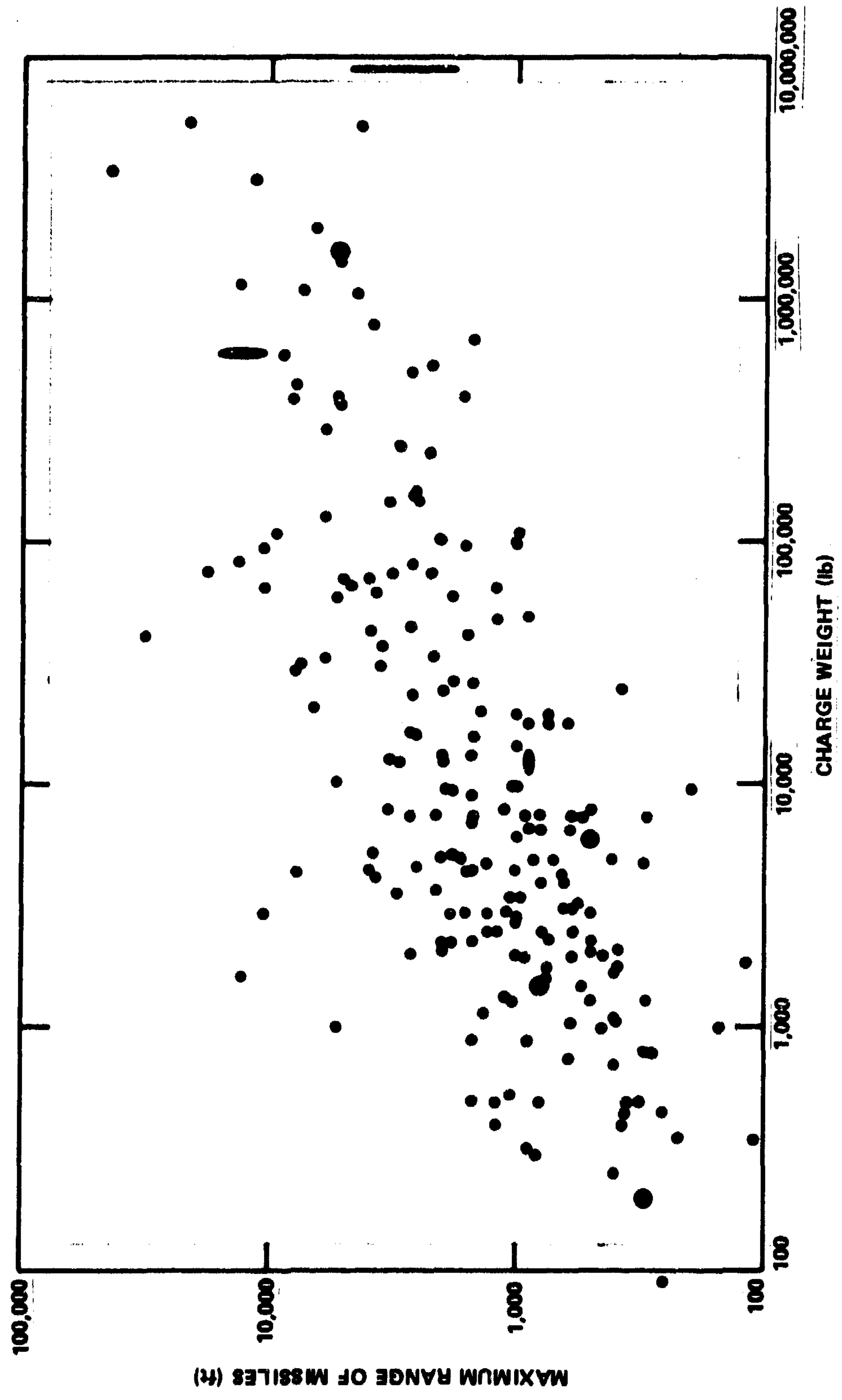

MAXIMUM RANGE OF MISSILES (ft)
100,000
10,000
1,000
100
CHARGE WEIGHT (lb)
100
1,000
10,000
100,000
1,000,000
10,000,000

Figure 8

The NESIP plans to make a large scale, instrumented test within the next few months which will hopefuly validate this proposed model. The test will also be used to determine whether other methods for estimating structure fragments can replace the method proposed here for predicting initial speeds of missiles (which aren't all fragments of ship structure).

APPENDIX

AN EXAMPLE PREDICTION

To illustrate the use of the proposed model, a prediction was made of the missile hazard from an actual test. The test ship was of riveted construction and hence this test had not been used to obtain data for the model. No concession was made for the riveted construction in the prediction of the number of massive missiles.* In this case, the apertures in the hull were well predicted by the model. The model would have predicted further hull opening only if the riveted connections had less than half the dynamic toughness that a welded connection would have had. Therefore, the predicted aperture (and thus the missile dispersion) was not sensitive to the method of construction in this particular case.

The limits of angular dispersion appeared to be adequately predicted. The model's type of distribution (uniform) of missile count within the actual limits also appeared to be reasonable. The predicted dispersion was over a range of 113 degrees in azimuth and 40 degrees in elevation. The actual ranges of angles estimated from movie viewing were within these predicted angular ranges.

The value of W_p was calculated to be 145 x 10^6 foot pounds, a value within the range of the test data previously analyzed. This value of W_p corresponds to a mean value of initial velocity for the three heaviest size groups of missiles of 206 feet per second. The values of mean and standard deviation of initial velocity for the smallest group of missiles were predicted to be 1,860 and 1,560 feet per second respectively. These

* The hull panel facing movie coverage hinged downward and did not separate, while the corrsponding panel on the opposite side of the ship came free.

statistics were predicted assuming a constant ratio of speeds between the two categories of size groups as W_p varies. The speed of missiles in the smallest size category was taken as normally distributed with the above values of mean and standard deviation but with a minimum of 980 feet per second, and the speed of larger missiles was taken as exponentially distributed with a mean value of 206 feet per second.

The expected numbers of missiles within each size group predicted to exit through the starboard aperture, based on a source volume of 1024 cubic feet are:

smallest size group	200 missiles
	133 missiles
	206 missiles
largest size group	282 missiles (as increased five fold)

At writing, drag coefficient data had not yet been analyzed. A majority of the missiles had been observed to tumble, but apparently very few sailed.

Analysis of movie coverage of the test indicated that few missiles splashed further than around 650 to 750 feet from the center of the explosion. Therefore, a study was performed to determine the ranges of drag coefficient, C_D, (taken as a constant for missiles in all three of the larger size groups) which would produce this observed result, depending on what number is taken as "few". The ranges of C_D corresponding to the precent p, of all missiles in the largest three size groups predicted to exceed the 650 to 750 foot distance is given below:

p	C_D
0.8	0.91 - 1.07
2.5	0.76 - 0.90
5	0.66 - 0.78

In calculating the above values, the drag retardation parameter was taken as equal to $r_d \frac{C_D}{t}$, where t is the ratio of missile volume to missile presented area and r_d is the ratio of density of air to density of missile. Lift was ignored on the presumption that its average effect is small for missiles tumbling many revolutions in a trajectory.

It was deemed reasonable to treat all of the larger size groups of missiles as having the same value of density and t, since steel was expected to predominate and because drag was expected to be dominated by its value at a missile orientation of flat-side-perpendicular-to-missile-trajectory. Thus t can be thought of as the effective thickness of a missile. A value of t of three-eights inches was used for the calculations.

To demonstrate application of the model, a horizontal target was chosen to be at sea level, extending from a distance 525 feet to a distance 575 feet from the center of the explosive, and 48 feet wide in the other horizontal direction. The above formulation of drag retardation parameter was used for steel missiles having $C_D = 1.0$. The percent of all missiles in the three large-size categories striking the target was found to be two tenths of one percent. The number* of hits per 600 square feet of target was predicted to be:

0.38 (impact energy at least 58 foot pounds)
0.30 (impact energy at least 350 foot pounds)
0.28 (impact energy at least 580 foot pounds)

Thus, if protection is provided for missiles with up to 350 foot pounds of translational kinetic energy, the target receives no more than about 0.30 hazardous missiles per 600 square feet (with 90% confidence).

*The probability of these estimates of missile hit counts being exceeded is about 10%

If the target is moved 100 feet farther away from the explosion center, the number* of hits per 600 square feet of target is predicted to be:

0.104 (impact energy at least 58 foot pounds)
0.084 (impact energy at least 350 foot pounds)
0.076 (impact energy at least 530 foot pounds)

*The probability of these estimates of missile hit counts being exceeded is about 10%

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BLAST/FRAGMENT HAZARDS ASSOCIATED WITH THE ACCIDENTAL DETONATION OF A MK 82 BOMB PALLET

by

Jerry M. Ward

Naval Surface Weapons Center

BLAST/FRAGMENT HAZARDS ASSOCIATED WITH THE ACCIDENTAL DETONATION OF A MK 82 BOMB PALLET

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ABSTRACT

As part of the Navy's Explosive Safety Improvement Program (NESIP), a test series was conducted to evaluate the maximum credible explosion (MCE) and the blast/fragment hazards for a pallet load of Mk 82 bombs (H-6 explosive) containing one donor and five acceptor bombs. Evidence that all acceptor bombs sympathetically detonated for all bomb pallet tests was obtained from high-speed photographic and ionization probe data. This result indicates that the MCE for a pallet of Mk 82 bombs is six bombs (the pallet load) for H-6 explosive. Pressure-distance results for the ranges 200-800 ft and fragment dispersal patterns for 30° sectors from 500-1000 ft range were obtained for three pallet orientations; nose-on, side-on, and tail-on. The pressure-distance curve generated from the airblast data indicates that the 1 psi level (acceptable overpressure hazard criterion) is attained at a range somewhat less than 600 ft. The hazardous fragment areal densities evaluated for the test site recovery area did not exceed the acceptable fragment hazard criterion (1 hazardous fragment per 600 ft^2 ground surface area) for any of the pallet orientations. Therefore the acceptable fragment hazard does not extend beyond 500 ft range. From a consideration of the blast and fragment hazard criterion, the acceptable hazard handling arc for a pallet load of Mk 82 (H-6 explosive) was determined to be approximately 600 ft.

Blast/fragment test results for the bomb/pallet hazard environment are compared with predictions developed for the NESIP technology base. Previously published fragment hazard predictions computed using single-bomb munitions effectiveness data are also included.

INTRODUCTION

Background: This work was performed as part of the Navy Explosive Safety Improvement Program (NESIP) at the Naval Surface Weapons Center (NSWC).

In the past, the Navy has operated under Explosive Safety Quantity Distance (ESQD) waivers at the tidewater port complexes during explosive handling operations for operations that were necessary to maintain fleet operational readiness requirements. The ESQD arc of 1250 ft. was established by the Department of Defense Explosive Safety Board (DDESB) for 30,000 lb. net high explosive weight. This requirement is applied to any quantity of fragmenting ordnance below this amount unless a specific acceptable hazard handling arc has been established. Because of this requirement, ESQD waivers have had to be issued for operations such as ordnance transfers for which the net explosive weight (NEW) involved was much less than 30,000 lbs., but for which no acceptable hazard handling arc had been established. The NESIP, as part of its mission, has been concerned with establishing these acceptable hazard handling arcs for various weapons systems and their associated handling operations (References 1-4). Reference 5 briefly describes the technology base being developed that can be used to perform these evaluations -- the main impact of the technology base is for developing an understanding of the blast/fragment problem, developing preliminary analysis methods, and designing tests.

The acceptable hazard handling arc for an explosion event is determined by the minimum range at which both blast overpressure and fragment hazard criteria are satisfied. These criteria are defined below.

(1) The blast overpressure should be less than 1 psi.

(2) The hazardous fragment flux evaluated for the ground surface area should be less than 1 hazardous fragment per 600 ft^2. A fragment is considered hazardous when it has an impact energy of 58 ft-lb or greater.

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The Mk 80 series of bombs are handled at tidewater port complexes. This phase of the study was initiated to determine the acceptable hazard for a pallet load of Mk 82 bombs. This paper describes the explosion testing results and the comparisons with predictions for the Mk 82 bomb pallet. Plans are to use the Mk 82 results to make more accurate predictions for the other bombs in the Mk 80 series and confirm these predictions by explosion testing.

Objective: The objective of this work was to determine the acceptable hazard handling arc for a pallet load of Mk 82 bombs (H-6 explosive) with one donor bomb. To accomplish this objective a combined experimental and analytical program was performed. Three aspects of the explosion event were addressed:

(1) The Maximum credible explosion (MCE) - Determine the number of acceptor bombs which sympathetically detonate in a pallet configuration.

(2) The blast environment for the MCE - Determine the pressure-distance curve produced by the MCE that includes the 1 psi overpressure regime.

(3) The fragment environment for the MCE - Determine the total fragment and the hazardous fragment areal distributions at the 500-1000 ft range for nose-on, side-on, and tail-on pallet orientations for the MCE.

Summary: The acceptable hazard handling arc for a pallet load of Mk 82 bombs (H-6 explosive) was determined to be approximately 600 ft. For the five pallet tests reported in this paper, all acceptor bombs in the pallet sympathetically detonated for the single donor bomb configuration selected. The pressure-distance curve generated from the airblast data indicates that the 1 psi level (the acceptable overpressure hazard criterion) is attained at a range somewhat less than 600 ft. Two prediction models indicated that the 1 psi level would occur at 480 ft and 550 ft. The hazardous fragment areal densities evaluated for the test site recovery area (30^{o} sectors for ranges from 500-1000 ft) did not exceed the acceptable fragment hazard criterion (1 hazardous fragment/600 ft^2) for any of the pallet orientations; nose-on, side-on, and tail-on. This means that the acceptable fragment hazard does not extend beyond a 500 ft range. Test predictions gave the acceptable fragment hazard range to vary from 425 ft to 765 ft according to pallet orientation.

The test results were surprising in that the blast criterion determined the acceptable hazard handling arc instead of the fragment criterion.

A comprehensive report that documents details of the predictive, test, and analytical methods plus the test data will be published as a NSWC technical report at a later date.

TEST DESCRIPTION

The explosion testing was performed at the West Valley Test Area, TERA, New Mexico Institute of Mining and Technology, Socorro, New Mexico. The general test setup is shown in Figure 1. The major elements of the field test layout include: bomb/pallet instrumentation, flash panels and fiberboard bundles at close range (25 ft and 75 ft range), fiberboard bundles at far range (500 ft and 520 ft range), recovery area (sectors 1-25), and airblast instrumentation. High speed cameras were used to instrument the bomb/pallet and the close-in flash panels fiberboard bundles.

There were six explosion tests in the series; one single bomb test (side-on orientation towards the recovery area) as a standard and five pallet tests (two nose-on, two side-on, and one tail-on orientation towards the recovery area). The pallet configuration is shown in Figure 2.

The donor bomb for each test was detonated with a C-4 booster in the nose well. The donor bomb was in the position indicated in Figure 2 (middle bomb, bottom row) for all pallet tests. No fuzes were present in either the donor or acceptor bombs.

Bomb/Pallet Instrumentation: The close-in early-time explosion events were recorded photographically and monitored by ionization gages to determine the sympathetic detonation sequence for the acceptor bombs in the pallet. The nose-on face of the pallet was viewed by a 1/4-frame high-speed (22,000 to 37,000 pictures per second) camera. This camera was at Station 4 in Figure 1. The side-on and tail-on faces of the pallet were viewed by 1/2-frame cameras (approximately 10,000 pictures per second - Stations 3 and 5 in Figure 1). Ionization probes were installed in the tail wells of the donor and acceptor bombs to register the arrival of the detonation front.

The explosion events were also documented photographically over a large field of view by cameras at Stations 8, 9, and 10 (See Figure 1). Camera 8 recorded the events at 5000 - 8000 frames per second and cameras 9 and 10 ran at 120 frames per second and 24 frames per second, respectively.

Flash Panels and Fiberboard Bundles at Close Range: For each of the tests a flash panel (4'x8'x0.050" - wxhxt, aluminum) was set up at 25 ft from ground zero and a flash-panel-faced-fiberboard bundle (4'x8'x4' - w x h x t) was erected at a distance of 75 ft. from ground zero. Cameras 6 and 7 (see Figure 1) recorded fragments passing through the 25 ft flash panel. Cameras 1 and 2 recorded fragment impacts on the front face of the 75 ft flash panel/fiberboard bundle. The data films were used to evaluate initial fragment velocities. In addition, the flash panel/fiberboard bundle at the 75 ft distance captured the impacting fragments to permit an independent calculation of fragment velocity based on measured fragment mass and dimensions.

Fiberboard Bundles at Far Range: Twenty-two fiberboard bundles (each with dimensions 4'x8'x1' - w x h x t) were erected in an alternating pattern at ranges from ground zero of 500 ft and 520 ft. This is shown schematically in the recovery area sectors 23 and 24, Figure 1. The bundles were set up to provide a measure of the low height fragment flux in the vertical plane at the 500 ft range.

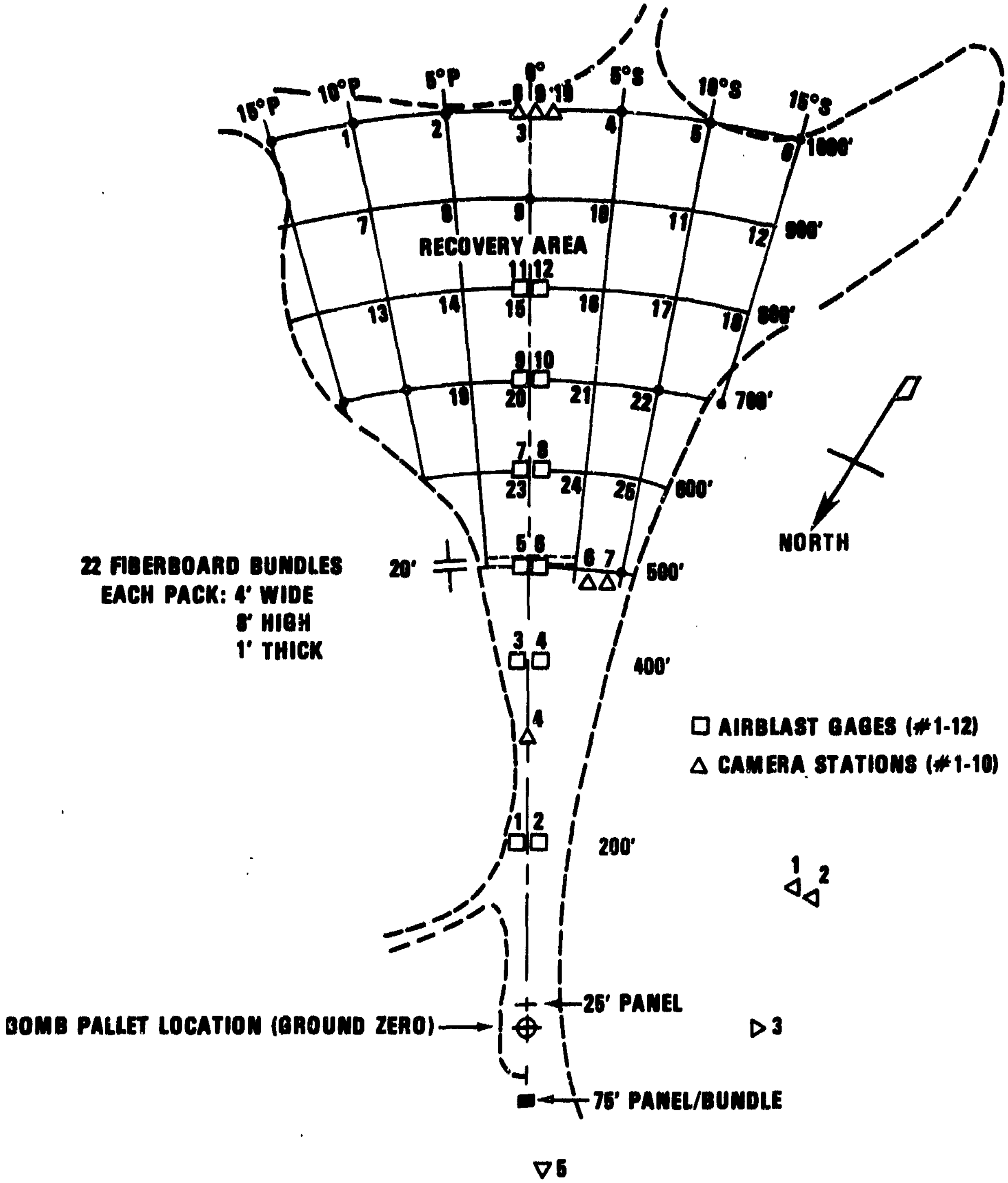
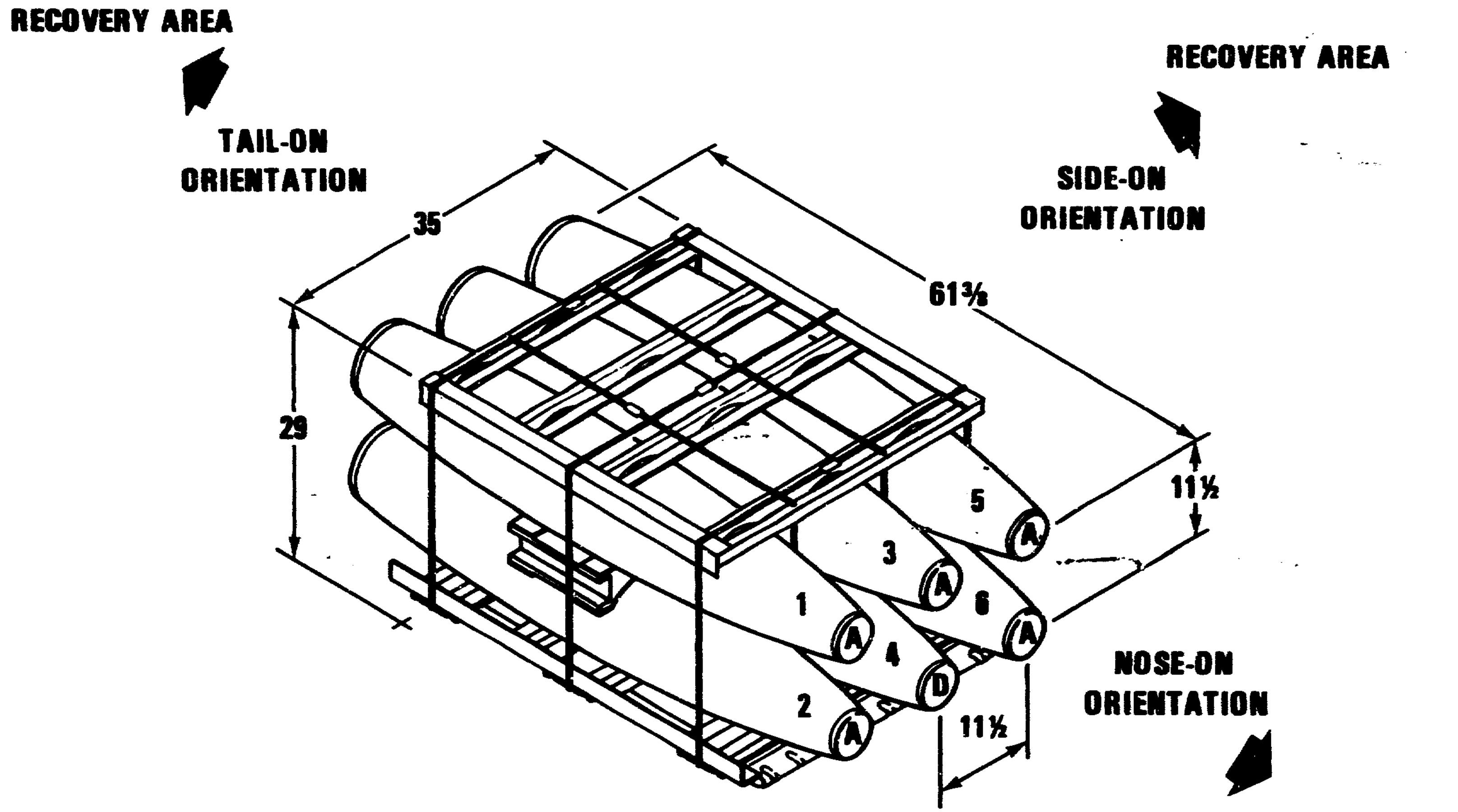


FIGURE 1. MK 82 BOMB PALLET TEST SETUP AT WEST VALLEY TEST AREA, NOSE-ON CONFIGURATION



NOTE: DIMENSIONS IN INCHES

D - DONOR BOMB (NOSE FUZED)
A - ACCEPTOR BOMB

FIGURE 2 MK 82-BOMB PALLET ORIENTATIONS

Recovery Area: The recovery area shown in Figure 1 is represented by the grid network (25 sectors). It is bounded by terrain contours as indicated in the figure by dashed lines. The recovery area is used to measure the fragment flux in the ground plane from 500 ft to 1000 ft for up to a 30^{o} total included angle.

Following each explosion event, a recovery team collected the fragments that landed in the recovery area. The fragment data were classified into three mass classes:

(1) Fragment mass $\leq$ 6 grams - For these fragments the number of fragments and the total mass of all the fragments collected in each recovery area sector were recorded.

(2) 6 grams < fragment mass < 28 grams - For these fragments the mass of each fragment collected was recorded and assigned to the proper recovery area.

(3) 28 grams < fragment mass - For these fragments the mass of each fragment collected was recorded along with the coordinates (R,θ) of the fragment location.

Because of the uncertainties in the exact initial impact points of the collected fragments -- the fragments did bounce to their final resting place -- the fragment impact energies were equated to the fragment energy value corresponding to the minimum radius boundary of the specific recovery area sector where the fragments were picked up.

Airblast Instrumentation: A team from NSWC made the airblast measurements at the TERA test site. The gages were deployed at six stations (two gages per station) as shown in Figure 1. The gage station locations ranged from 200 ft to 800 ft from ground zero. The gages (LC-33 pencil type) were mounted on TEFLON inserts that were secured to steel baffles. The gages were installed a nominal two feet above the ground. The signals were processed by PCB electronics and recorded on a magnetic tape recorder. The upper frequency response of the recording system was 20 KHz.

Before each series of tests (conducted in groups of two) all the airblast gages were field calibrated, dynamically, through the recording system. This procedure provided a comparison with the gage laboratory calibration and also gave an indication that the acquisition system was performing properly.

TEST RESULT COMPARISON WITH PREDICTIONS

Only the results that are directly related to the three major aspects of the hazard associated with the accidental detonation of a pallet load of Mk 82 bombs are presented here:

(1) The Maximum credible explosion

(2) The airblast environment

(3) The fragment environment

These results establish the acceptable hazard handling arc for the bomb pallet configuration tested and they contribute to the continual verification and updating procedure for the predictive techniques being developed by NESIP (Reference 5).

The Maximum Credible Explosion: The location of the donor bomb (middle bomb, bottom row) in the pallet is indicated in Figure 2. This donor site was selected because it is the best position to initiate sympathetic detonation among the most acceptor bombs in the pallet. For all bomb pallet tests (H-6 explosive), all acceptor bombs sympathetically detonated. Two different instrumentation methods were used in an effort to make this determination: (1) high speed photography and (2) ionization probes.

Figure 3 provides the most dramatic indication that all five acceptor bombs sympathetically detonated. This figure is a photograph of several frames of film from the 1/4-frame camera viewing the nose-on face of the pallet for pallet test 1. The film records the first light of the donor bomb and follows the detonation sequence for the acceptor bombs. The circles have been added to the photograph to show the original locations of the bomb noses in the pallet. The figure indicates that following time zero (designated as picture 0), the three near-neighbor acceptors (bombs 2, 3, and 6 - see Figure 2) had sympathetically detonated by picture #6, whereas the two far-neighbor acceptors (bombs 1 and 5) sympathetically detonated by picture #9. Film data such as this provided detonation times at the nose of the acceptor bombs for most of the tests.

The ionization probes were mounted in the tail wells of the donor and acceptor bombs to provide detonation front arrival times at the bomb tail locations. The detonation time results obtained from the photographic film and the ionization probe signals are summarized in Table 1. For purposes of comparison the detonation wave travel time (using 25,000 ft/s detonation velocity for H-6) from the donor bomb nose well to the tail well should be approximately 150 μs. Note in Table 1 that the photographic data consistently indicates that the near-neighbor acceptor bombs sympathetically detonated before the far-neighbor acceptor bombs. However, the ionization probe data only shows that the acceptor bombs detonated. The ionization probe time data do not appear to give reasonable times for acceptor bomb detonations.

The conclusion that all five acceptor bombs sympathetically detonated on each pallet test was also indicated by the post-test site inspections and by an analysis of the explosive yield required to generate the airblast pressure data.

The Airblast Environment: The airblast pressure-time histories were reduced using the NSWC (R15) data processing system that has an HP 9825 desktop computer with a NICOLET digital oscilloscope and an IDEAS tape drive unit. A typical pressure-time waveform is shown in Figure 4. The major components of the recorded signal are shown in the figure: (1) the ground shock arrival at the gage, (2) the shockwave arrivals at the gage from passing fragments, (3) the blast wave arrival at the gage, (4) the peak overpressure for the wave, (5) the positive phase of the wave, and (6) the negative phase of the wave.

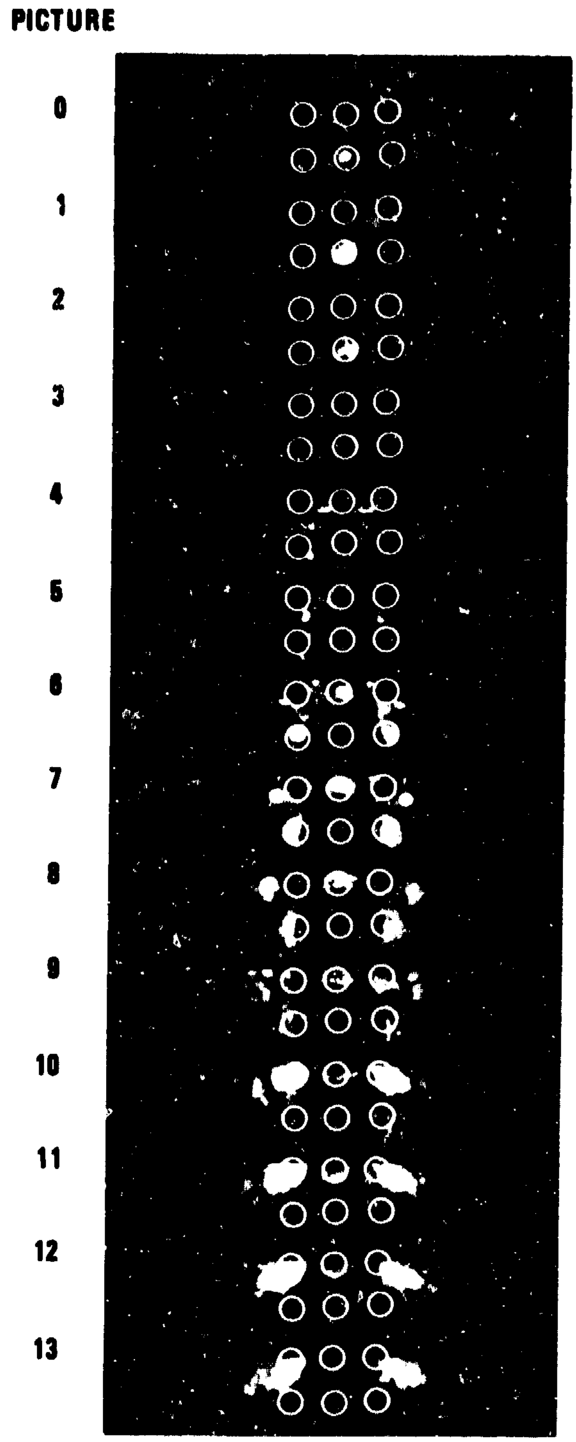
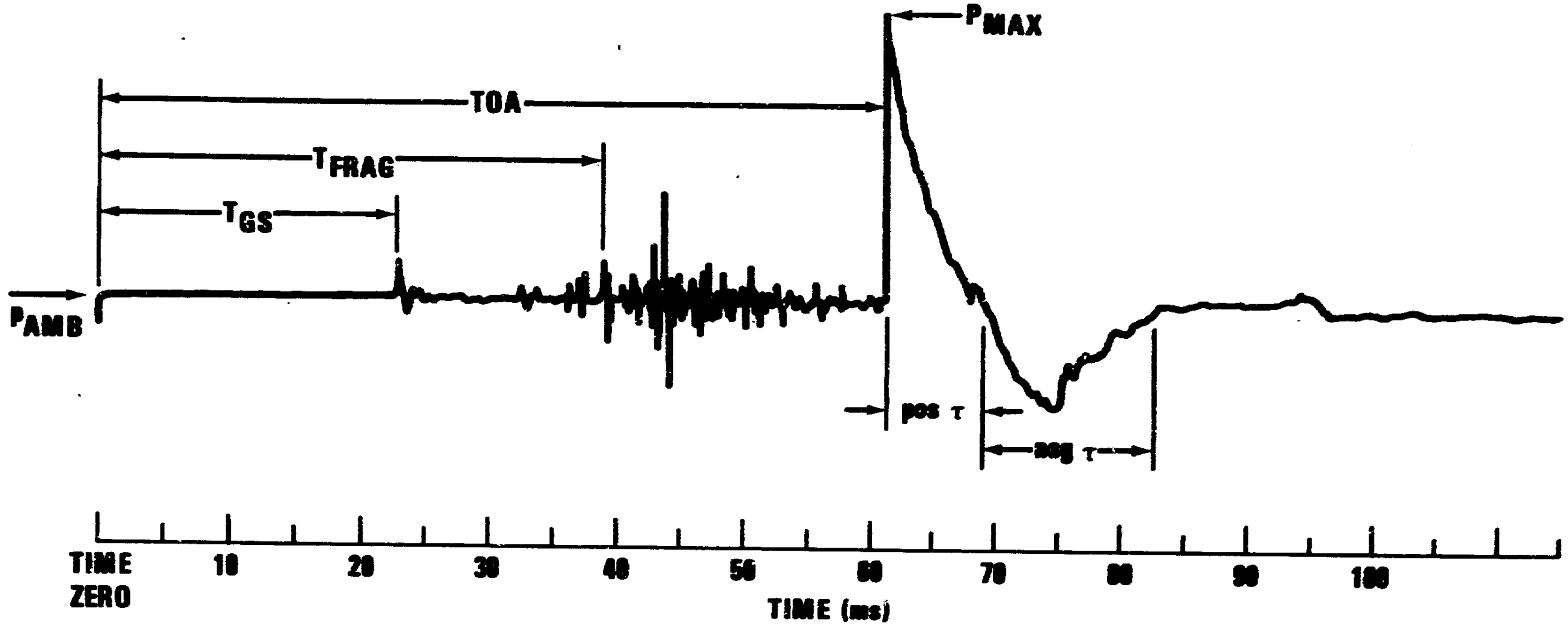


FIGURE 3. SYMPATHETIC DETONATION SEQUENCE FOR MK 82 BOMB PALLET TEST #1 (27 MICROSECONDS BETWEEN PICTURES)

TABLE I
PHOTOGRAPHIC AND IONIZATION PROBE DATA FOR ACCEPTOR BOMB SYMPATHETIC DETONATION SEQUENCE

DONOR	DETONATION SIGNAL ARRIVAL TIME (μsec)				
	PALLET 1 SIDE-ON	PALLET 2 NOSE-ON	PALLET 3 TAIL-ON	PALLET 4 SIDE-ON	PALLET 5 NOSE-ON
BOMB 4					
PHOTO (NOSE)*	0	0	0	0	0
ION (TAIL)*	—	118 ± 4	138 ± 4	146 ± 4	138 ± 4
NEAR-NEIGHBOR ACCEPTORS					
BOMB 2					
PHOTO (NOSE)	162 ± 14	138 ± 14	***	143 ± 18	185 ± 23
ION (TAIL)	187 ± 4	110 ± 4	115 ± 4	190 ± 4	175 ± 4
BOMB 3					
PHOTO (NOSE)	162 ± 14	138 ± 14	***	143 ± 18	185 ± 23
ION (TAIL)	192 ± 4	112 ± 4	72 ± 4	190 ± 4	195 ± 4
BOMB 6					
PHOTO (NOSE)	162 ± 14	138 ± 14	***	143 ± 18	185 ± 23
ION (TAIL)	166 ± 4	105 ± 4	85 ± 4	182 ± 4	195 ± 4
FAR NEIGHBOR ACCEPTORS					
BOMB 1					
PHOTO (NOSE)	242 ± 14	221 ± 14	***	179 ± 18	324 ± 23
ION (TAIL)	227 ± 4	218 ± 4	171 ± 4	178 ± 4	200 ± 4
BOMB 5					
PHOTO (NOSE)	242 ± 14	221 ± 14	***	179 ± 18	324 ± 23
ION (TAIL)	190 ± 4	211 ± 4	214 ± 4	173 ± 4	180 ± 4

*UNCERTAINITY IS SET EQUAL TO ONE-HALF THE INTER PICTURE TIME.
**UNCERTAINITY IS SET EQUAL TO TIME DIFFERENCE BETWEEN DIGITIZED POINTS.
***NO DATA FILM WITH TIMING FOR A NOSE-ON VIEW OF THE PALLET WAS OBTAINED FOR THIS TEST. ONE SPLIT FRAME CAMERA (PROBABLY 9,000 PICTURES/S) DID SHOW THE FIVE ACCEPTOR BOMB FIREBALLS. THE NEAR-NEIGHBOR FIREBALLS WERE LARGER IN DIAMETER THAN THE FAR-NEIGHBOR FIREBALLS.



T_{GS} – GROUND SHOCK ARRIVAL TIME

T_{FRAG} – FRAGMENT SHOCK ARRIVAL TIME

TOA – AIR BLAST ARRIVAL TIME

P_{AMB} – AMBIENT PRESSURE

P_{MAX} – MAXIMUM OVERPRESSURE

pos τ – POSITIVE DURATION

neg τ – NEGATIVE DURATION

FIGURE 4. TYPICAL PRESSURE-TIME WAVEFORM RECORD

An example of the pressure-time histories recorded at each gage station is shown in Figure 5 for the first pallet test, side-on orientation. The records given in Figure 5 are quite similar to the records obtained for the other side-on orientation test and the tail-on orientation test; pallet tests 4 and 3, respectively. However, neither set of nose-on orientation records, pallet tests 2 and 5, had such numerous fragment shockwave arrivals as indicated in Figure 5. The records for pallet test 2 (a nose-on orientation) are given in Figure 6 for comparison. This comparison is in agreement with the pallet test fragment data that the fragment flux from the nose-on orientation was less than the fragment flux from the side-on and tail-on orientations.

The pressure-distance data scaled to sea-level conditions for all the bomb/pallet tests are presented in Figure 7. The single bomb data were scaled up to six bombs (a pallet load). A power law least squares fit for all the pallet data is also included in this figure -- the single bomb data (denoted by squares) did not contribute to the fit. Power law least square fits were also made for each pallet test. The fitted curves for the nose-on and tail-on orientation tests fall between the curves for the two side-on tests. The shot-to-shot variation of the data is greater than the effect of pallet orientation.

Figure 8 provides a comparison of the power law least squares fit to the airblast data (including the 95% confidence intervals for the predicted mean values of the pressure for each range value) with Unified Theory of Explosions (UTE) predictions (Reference 6) and the Blast Effects Computer (BEC) predictions (Reference 7). The UTE prediction (part of the NESIP technology base Reference 5) agrees quite well with the data in this range. The BEC curve is shifted downward. It should be pointed out, however, that both prediction curves fall within the interval of two standard deviations of the fitted data curve; that is, within the scatter of 95% of the data.

The airblast data were examined to determine the range at which 1 psi overpressure occurs -- the acceptable hazard criterion for blast. The predicted and experimentally determined results are listed below.

Predictions

UTE -- 1 psi at 550 ft

BEC -- 1 psi at 480 ft

6. F. B. Porzel, "Introduction to a Unified Theory of Explosions," Naval Ordnance Laboratory, White Oak, Silver Spring, MD, NOLTR 72-209, Sep 1972.

7. L. E. Fugelo, L. M. Weiner, and T. H. Shiffman, "Explosion Effects Computation Aids," Final Report GARD Proj. No. 1540, Contract DAHC-04-72-0012, General American Research Division, General American Transportation Corp., Niles, IL, Jun 1972.

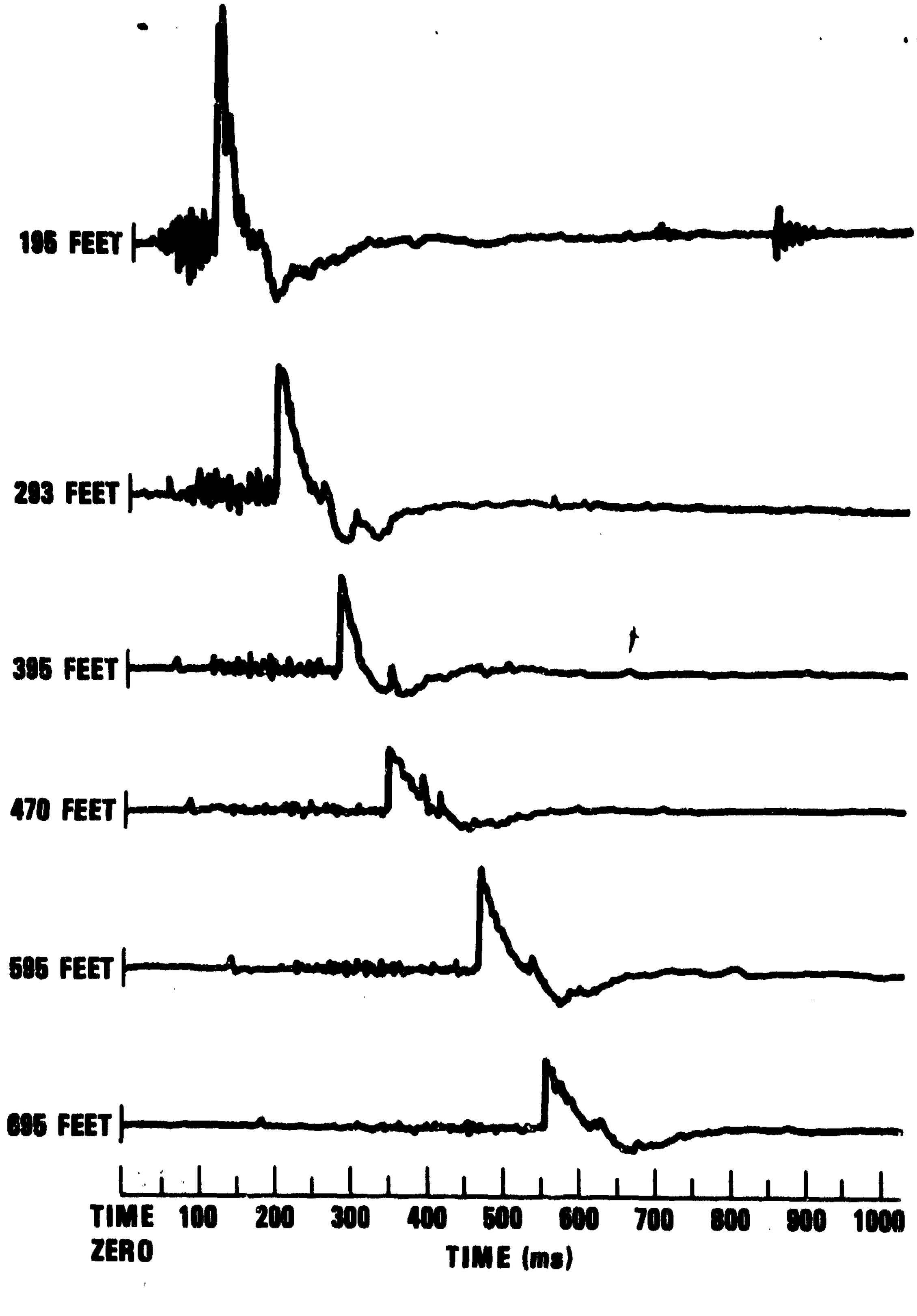


FIGURE 5. PRESSURE-TIME WAVEFORMS FROM MK 82 BOMB PALLET TEST 1, SIDE-ON CONFIGURATION

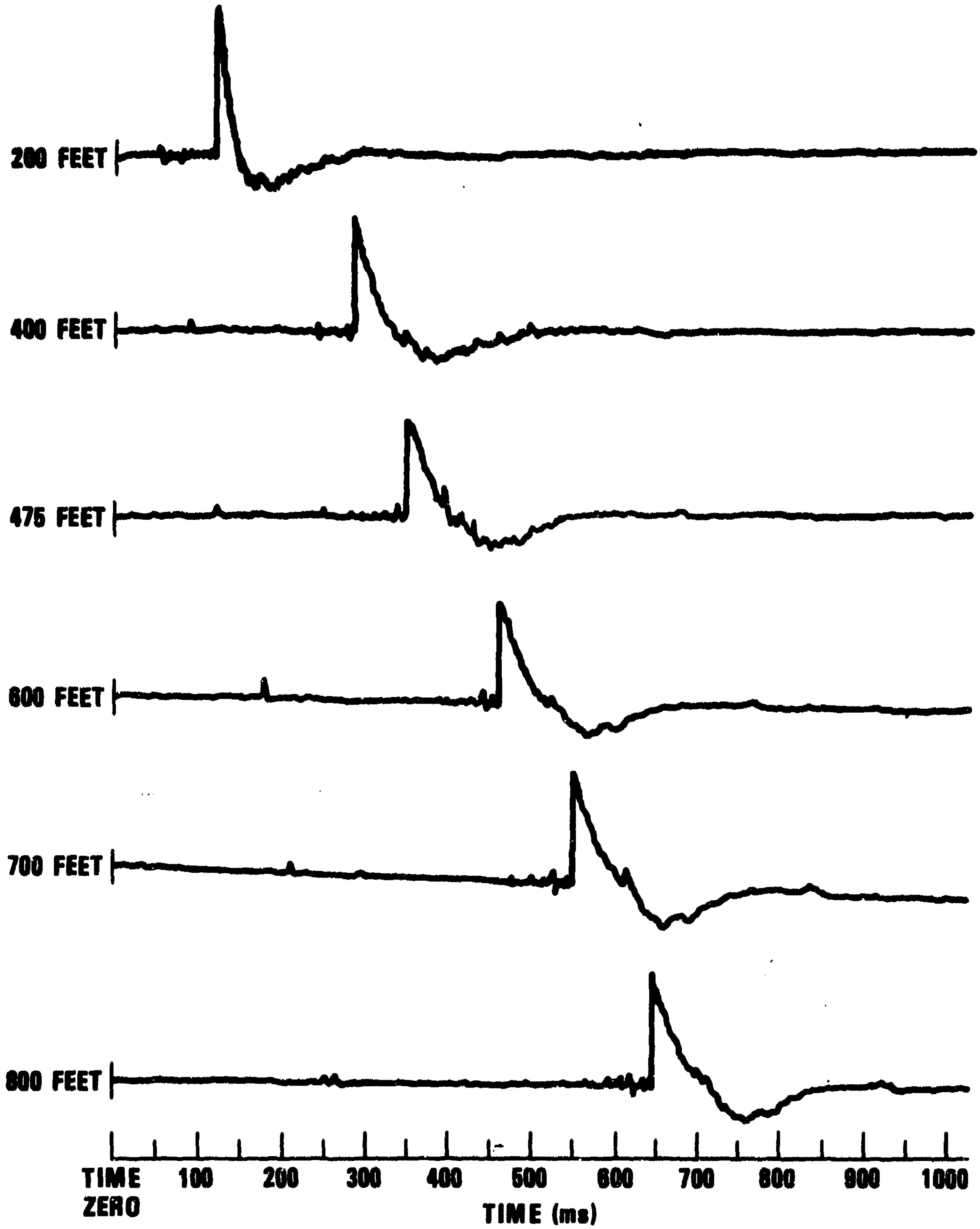


FIGURE 6. PRESSURE-TIME WAVEFORMS FROM MK 82 BOMB PALLET TEST 2, NOSE-ON CONFIGURATION

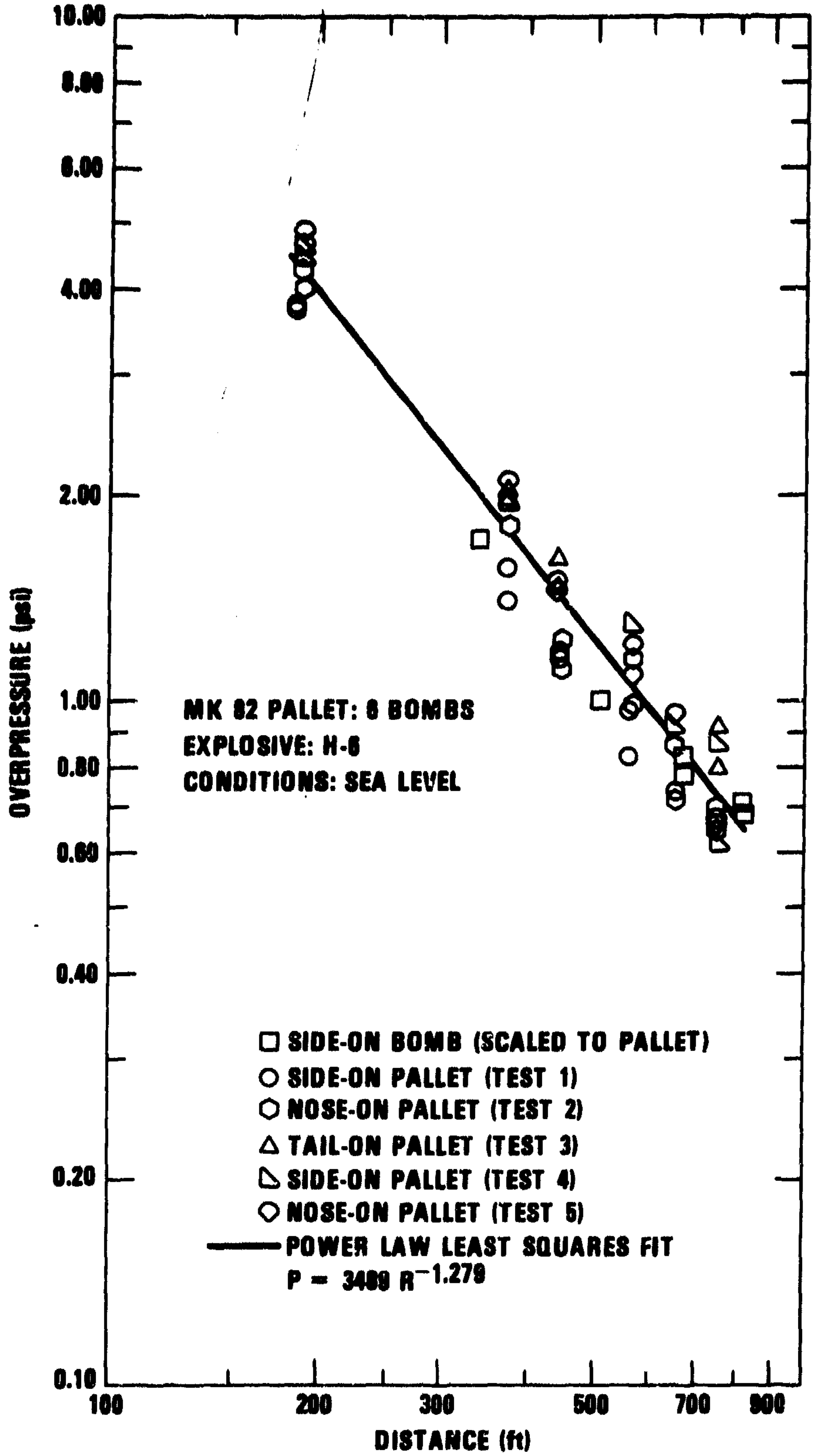


FIGURE 7. MK 82 BOMB PALLET AIRBLAST DATA

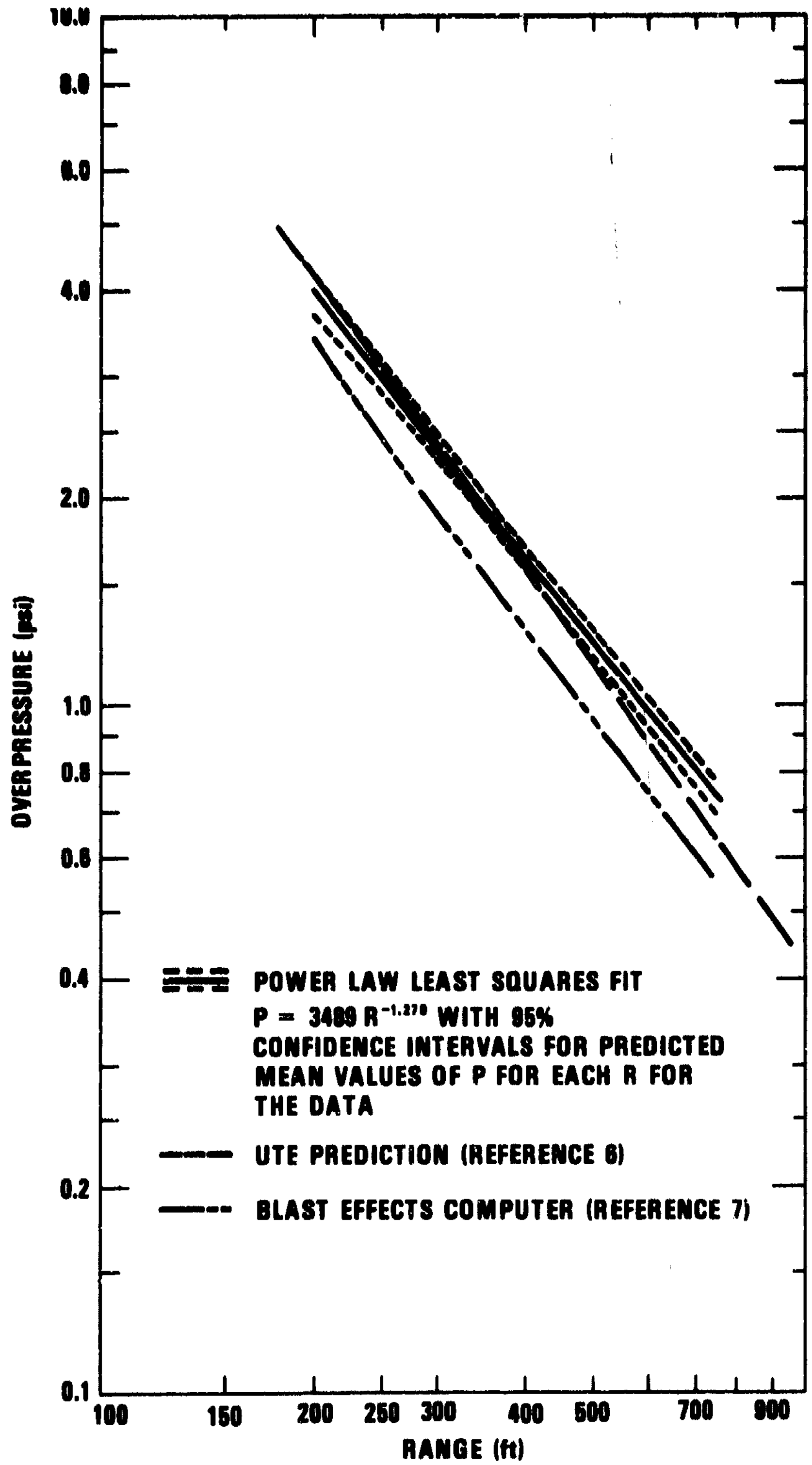


FIGURE 8. COMPARISON OF MK 82 PALLET AIRBLAST DATA FIT WITH PREDICTIONS

Data

Power law least squares fit -- 1 psi at 590 ft

95% confidence interval for predicted mean

$$582 \text{ ft} < R < 622 \text{ ft}$$

95% confidence interval for data

$$475 \text{ ft} < R < 725 \text{ ft}$$

Using these predicted and experimental results as a guide, the recommended acceptable hazard range for blast is 600 ft. This is not the most conservative choice, but it is a realistic one.

The Fragment Environment: The total numbers of fragments collected for each recovery area sector are displayed in Figure 9 for all five bomb pallet tests. The total fragment numbers listed represent fragments from all three mass groups: 0-6 gram, 6-28 grams, and greater than 28 grams. The trajectories of fragments that were stopped by the vertical fiberboard bundles at the 500 ft/520 ft range (located in recovery area sectors 23 and 24 - Figure 1) were estimated and these fragments were added to the counts given in Figure 9. The numbers of hazardous fragments allowed per recovery area sector (so as not to exceed the acceptable hazard criterion of one hazardous fragment per 600 ft^2) have been added to the figure. It is obvious from Figure 9 that if all the fragments collected were considered hazardous (impact energy greater than 58 ft lb) then the acceptable hazard range for fragments would be beyond 1000 ft.

In order to determine the proportion of hazardous fragments to total fragments, the impact energies of the recovered fragment must be known. These impact energies were estimated by ballistic trajectory calculations. A particle model computer code with three-degrees-of-freedom* and variable drag coefficient was used. Instead of computing the particular trajectory required to place a fragment at its recovered location, which would have taken many iteractions compounded by the fact that many fragments were collected, a series of ballistic trajectories were computed which were used to represent the bounding fragment trajectories. The series of trajectories for the steel bomb fragments are outlined below.

(1) Twelve fragment masses were selected

10-15-20-25-30-40-50-60-70-80-90-100 grams

(2) Twenty initial angles of elevation** were chosen for each mass
(-5)-(-2)-(-1)-0-1-2.5-5-10-15-20-22.5-25-27.5-30-35-40-50-60-70-80 degrees

*No wind velocity components (such as cross winds) were included, so the trajectory calculations only involved two-degrees-of-freedom.

**Negative angles of elevation were included to account for the difference in elevation between ground zero and the recovery area. The recovery area was ~19' lower than ground zero.

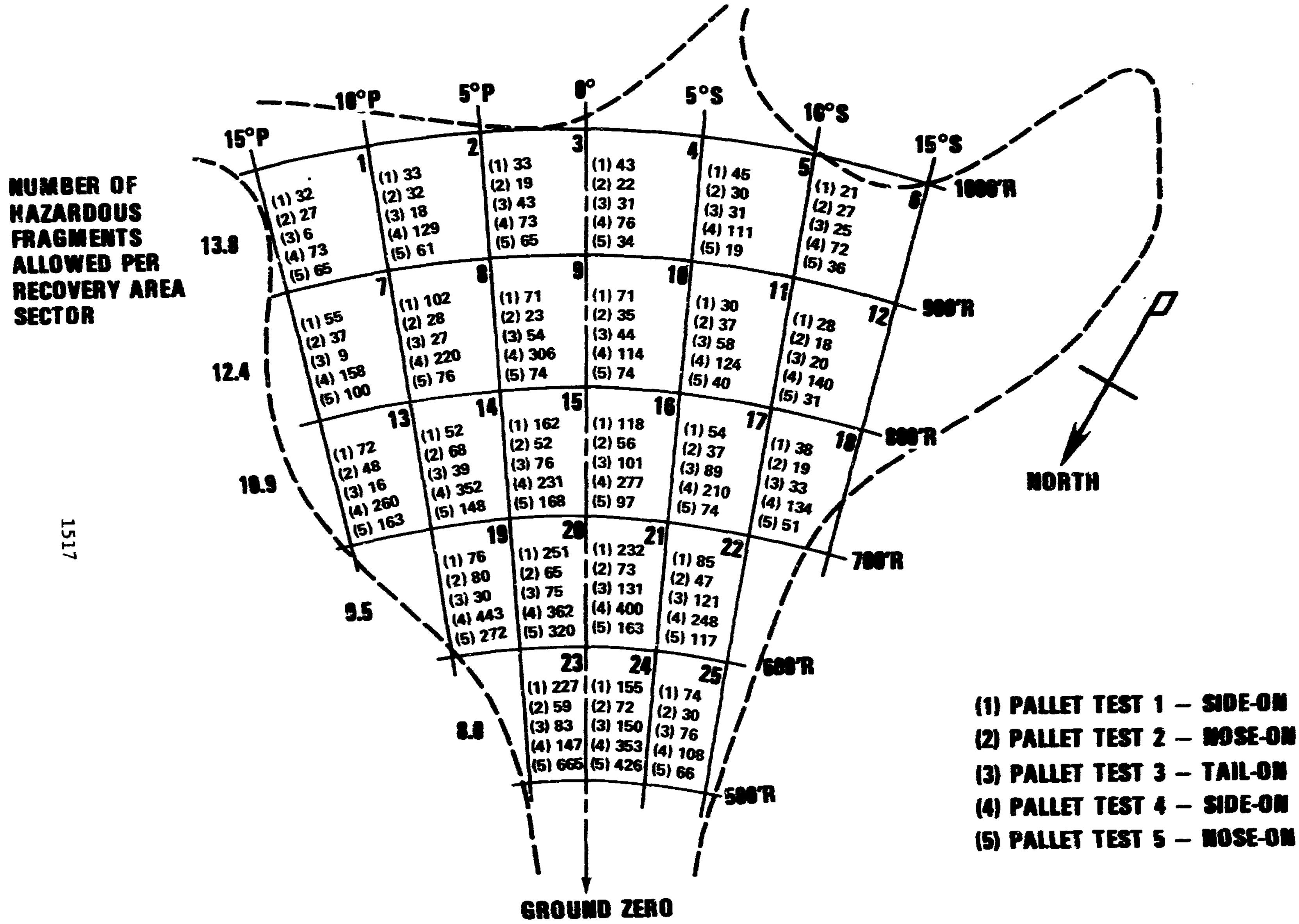


FIGURE 9. TOTAL NUMBER OF FRAGMENTS COLLECTED PER RECOVERY AREA SECTOR FOR THE MK 82 PALLET TESTS

Additional input conditions that are required in order to make trajectory calculations are average presented area, drag coefficient, and initial velocity for each fragment. These parameters are discussed in the next several paragraphs.

The average presented areas for the fragments were computed from the fragment masses using the relationship $M = KA^{3/2}$ where K is called the frag drag factor. The value of K evaluated for Mk 82 bombs was used for both the single bomb and pallet configurations.

The fragment drag coefficient versus Mach number relation was taken from Reference 8 for shell fragments.

An initial fragment velocity of 8000 ft/s was estimated from the single bomb test and 11,500 ft/s was estimated from each of the bomb pallet tests. These values were determined from the fragment time-of-arrival data obtained from the flash panels/fiberboard bundles located at close range (25 ft and 75 ft from ground zero). A straight line fragment trajectory path with an exponential velocity decay was used to make the conversion from average velocity to initial velocity. The best correlation for initial velocity that corresponded with times of arrival at both the 25 ft flash panels and the 75 ft flash panel/fiberboard bundles was for fragments in the mass range from 1-5 grams. The 8000 ft/s value estimated for the single bomb (side-on orientation towards ground zero) agrees quite well with the side-spray portion of the Mk 82 bomb effectiveness data. However, the 11,500 ft/s value for the bomb pallet initial fragment velocity is ~1½ times larger than the single bomb value. This result agrees qualitatively with the data obtained in Reference 9 in which initial fragment velocities from 155 mm projectile stacks were reported to be about twice the value obtained for single projectile tests -- these high velocities occurred in jets that emanated from "interaction areas (Reference 9)" that are the regions between the projectiles. For a pallet load of Mk 82 bombs in the normal horizontal configuration (see Figure 2) these high velocity fragments (~11,500 ft/s) were measured for all three orientations tested (nose-on, side-on, and tail-on). The higher velocity (jet velocity) was selected for the pallet configuration to evaluate the fragment hazard even though obviously not all fragments would have this enhanced initial velocity.*

The trajectory calculations were used to establish "fragment hazard factors (Reference 2)" which estimate the portion of the total number of fragments collected in a region that impacted with a hazardous energy (>58 ft-lb).

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8. D. J. Dunn, Jr., and W. R. Porter, "Air Drag Measurements of Fragments," BRL Memorandum Report No. 915, Aug 1955.

9. R. T. Ramsey, J. G. Powell, Jr., and W. D. Smith III, "Fragment Hazard Investigation Program" NSWC/DL TR 3664, Oct 1978.

* In fact, to ascribe the high jet velocity to all the bomb fragments would require approximately 2 1/2 times the energy available upon bomb detonation.

The fragment hazard factor (F_H) is based on the following model. For each fragment impact location out to the maximum range, there are two trajectory solutions -- the low-angle trajectory and the high-angle trajectory. The impact energies for these two trajectory solutions for the same range can be quite different. As an example, for a 10 gram steel fragment (Mk 82 fragment parameters) with an initial velocity of 8,000 ft/s impacting at 800 ft, the low-angle trajectory impact energy is approximately 60 ft-lb whereas the high-angle trajectory impact energy is about 3 ft-lb. Because of this, it is necessary to determine the proportion of low-angle trajectory to high-angle trajectory impacts in a given recovery area sector. This was accomplished using computed trajectory results such as displayed in Figure 10. In this figure, the impact range is plotted as a function of launch elevation angle* for the same bomb fragment as described above. If the fragments are uniformly distributed with respect to launch elevation angle, then Figure 10 gives the result that 8.8% of the fragments landing in recovery area sectors #23-25 (between a range of 500 ft to 600 ft) arrived by a low-angle trajectory.

A basic assumption with the fragment hazard factor (F_H) model is that the fragment mass source is uniformly distributed with respect to elevation angle. For the single bomb test (side-on orientation), the basic assumption is satisfied; however, for a specific pallet test with the donor bomb location the basic assumption is not satisfied. For example, if only the donor bomb had detonated, then more bomb case mass would be available for high-angle trajectories than for low-angle trajectories because the donor bomb was in the lower bomb row (Figure 2). However, all acceptor bombs sympathetically detonated for the pallet tests which changed the initial fragment flux distribution. Considering the different possible pallet orientations (nose-on, side-on, tail-on, and any intermediate orientation) and considering the many possible detonation sequences (and timing) for the acceptor bombs with the formation of the high velocity jets, then the uniform mass distribution with respect to elevation angle is used as a representation of an average mass distribution. At present, any mass distribution relative to elevation angle derived for a particular pallet orientation and bomb spacing (related to sympathetic detonation sequence and timing) appears to be too specific (and arbitrary) to be useful.

The fragment hazard factor (F_H) -- for a specific fragment mass, average presented area, drag coefficient function, and initial velocity -- is established for a specific recovery sector** using the three definitions given below.

*The negative launch elevation angles are included in Figure 10 to account for the test site terrain.

**F_H variation with azimuth is not included. Therefore, recovery area sectors 23-25 (Figure 1) all have the same value of F_H for the same fragment.

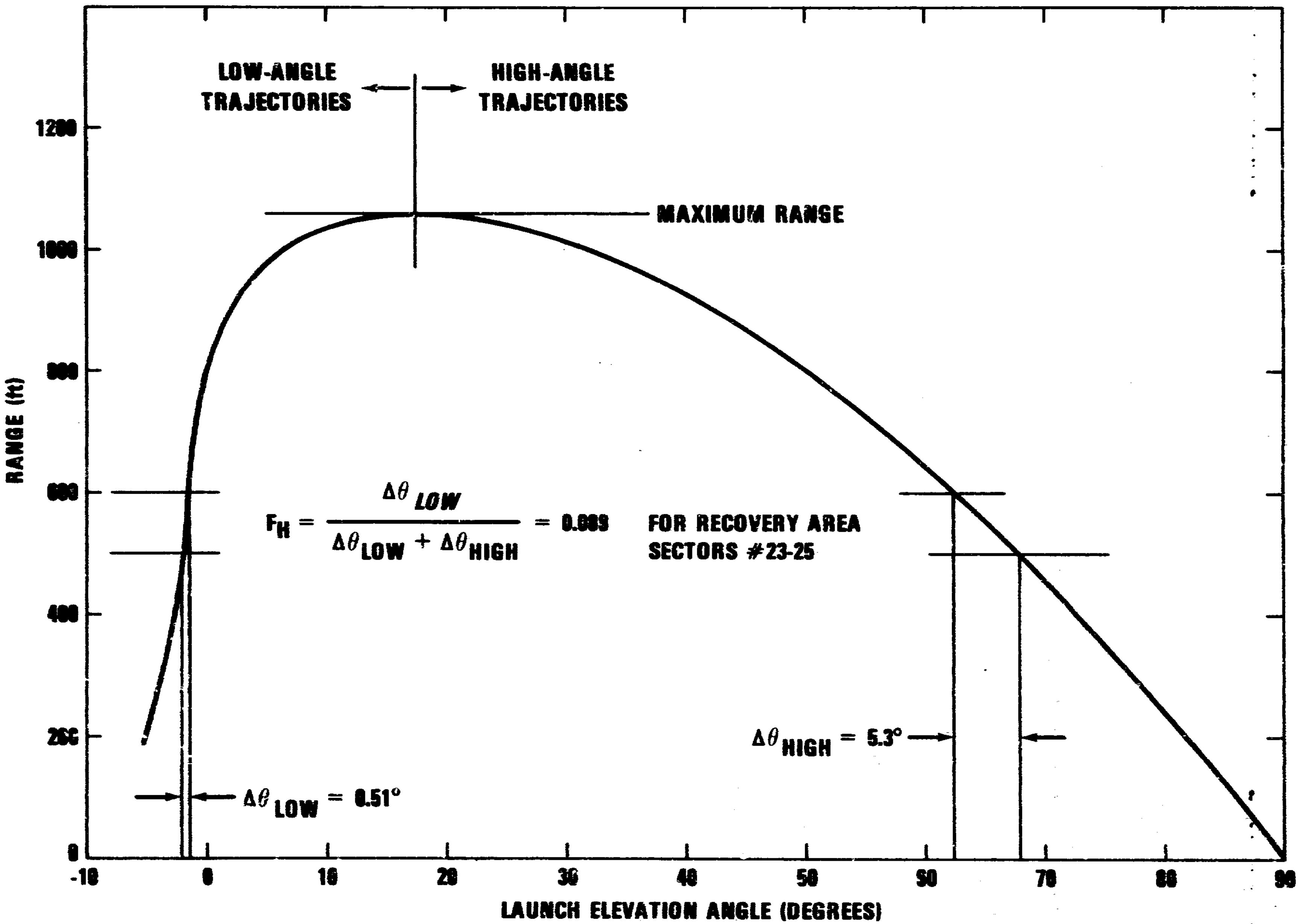


FIGURE 10. IMPACT RANGE VS. LAUNCH ANGLE FOR 10 GRAM FRAGMENT WITH INITIAL VELOCITY OF 8000 FT/SEC

(1) If both the low-angle and high-angle trajectories produce hazardous fragment impact energies (> 58 ft-lb), then $F_H = 1$.

(2) If neither the low-angle nor the high-angle trajectories produce hazardous fragment impact energies, then $F_H = 0$.

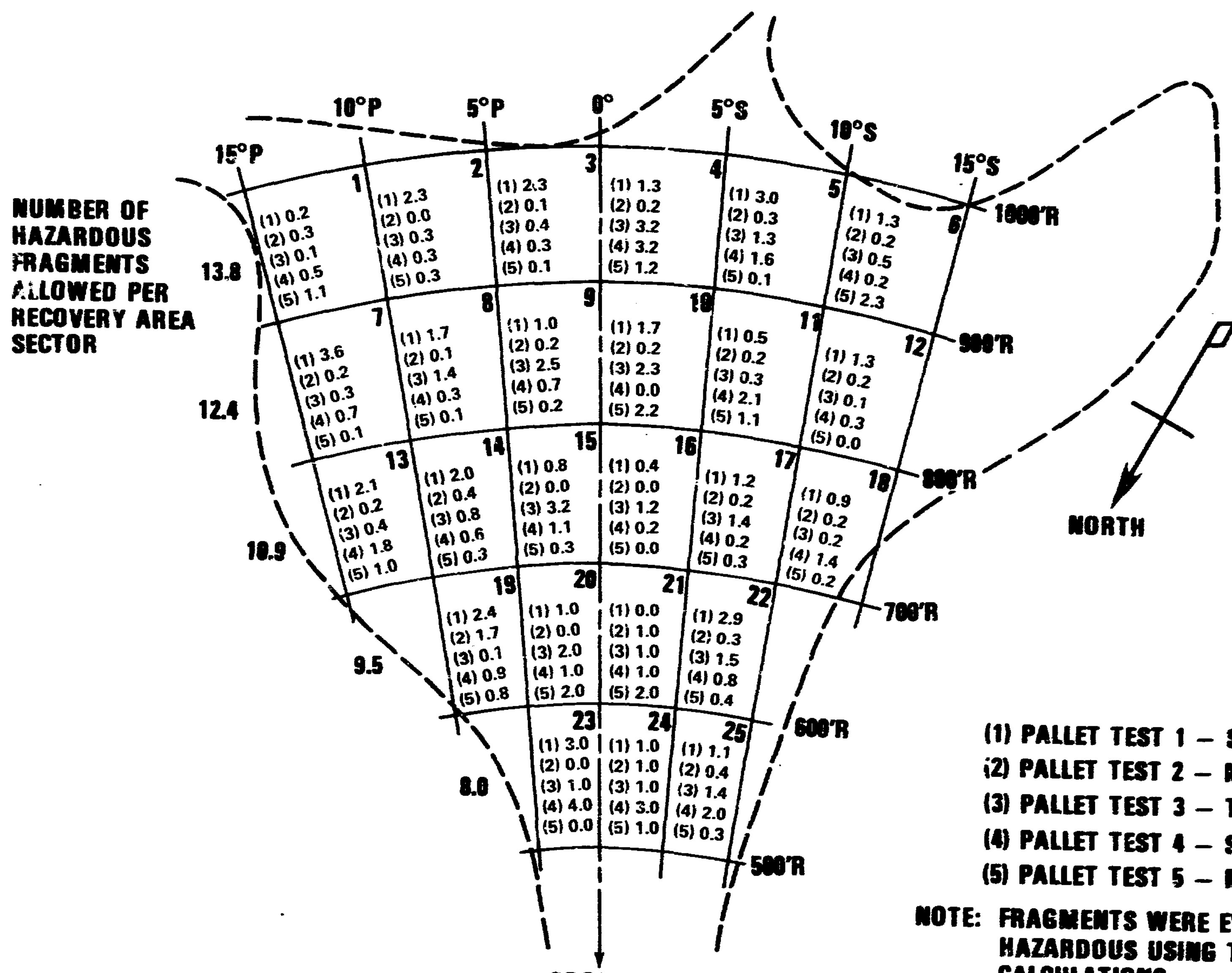
(3) If the low-angle trajectory produces a hazardous fragment impact energy but the high-angle trajectory does not, then F_H is set equal to the proportion of low-angle to total angle (low-angle plus high-angle) trajectories computed for the particular recovery area sector.

Separate tables of fragment hazard factors were set up for the single bomb test and the series of pallet tests. Hazardous fragment distributions were obtained by applying these factors individually to the recovered fragments. The hazardous fragment distributions for the five pallet tests are given in Figure 11. From a comparison of Figures 9 and 11, it is obvious that most fragments were evaluated to be non-hazardous. This figure indicates that the criterion for numbers of hazardous fragments allowed per recovery area sector was not exceeded anywhere in the recovery area for any of the pallet tests -- in fact the hazardous fragment criterion was not exceeded for the sum of hazardous fragments for all five pallet tests. As with the data reported in Figure 9, all fragments stopped by the vertical fiberboard bundle at the 500 ft./520 ft. ranges were added to the counts in Figure 11 (if they were evaluated to be hazardous).

Figure 12 presents plots of the average hazardous fragment areal densities as functions of range for the five pallet tests. None of the test data approach the fragment hazard criterion within a factor of two at 500 ft. The most hazardous pallet orientation is side-on as indicated in Figures 11 and 12. The two sets of side-on pallet data are combined in Figure 13 and a Student-t evaluation giving the 95% confidence intervals for the mean values is presented. The analysis of the data indicates that the Mk 82 bomb pallet is an acceptable fragment hazard beyond 500 ft. (the close-in range of the data).

Figure 14 gives the predicted curves for the hazardous fragment areal densities as functions of range for the pallet tests. The model used, FEN, has been described in References 5, 10 and 2 as part of the NESIP technology base. It should be pointed out that the hazardous fragment areal densities given by the FEN model are based on trajectory-normal areas for low-angle trajectory fragments and not horizontal ground surface area for both low-angle and high-angle trajectory fragments as are the collected data (Figure 12). The FEN model results shown in Figure 14 include polar zone corrections for mass and velocity distributions provided by Mk 82 bomb effectiveness data. These prediction curves do not account for the high fragment velocity (~11,500 ft/s) obtained from the pallet test data. The FEN model predicitions in the figure for the acceptable hazard fragment range for the three pallet orientations are: nose-on - 550 ft., side-on - 765 ft., and tail-on - 425 ft.

10. F. B. Porzel, "Design of Lightweight Shields Against Blast and Fragments," Minutes of the 17th Explosives Safety Seminar, Department of Defense Explosives Safety Board, 14-16 Sep 1976.



(1) PALLET TEST 1 — SIDE-ON
(2) PALLET TEST 2 — NOSE-ON
(3) PALLET TEST 3 — TAIL-ON
(4) PALLET TEST 4 — SIDE-ON
(5) PALLET TEST 5 — NOSE-ON

NOTE: FRAGMENTS WERE EVALUATED TO BE HAZARDOUS USING TRAJECTORY CALCULATIONS

FIGURE 11. NUMBER OF HAZARDOUS FRAGMENTS PER RECOVERY AREA SECTOR FOR THE MK 82 PALLET TESTS

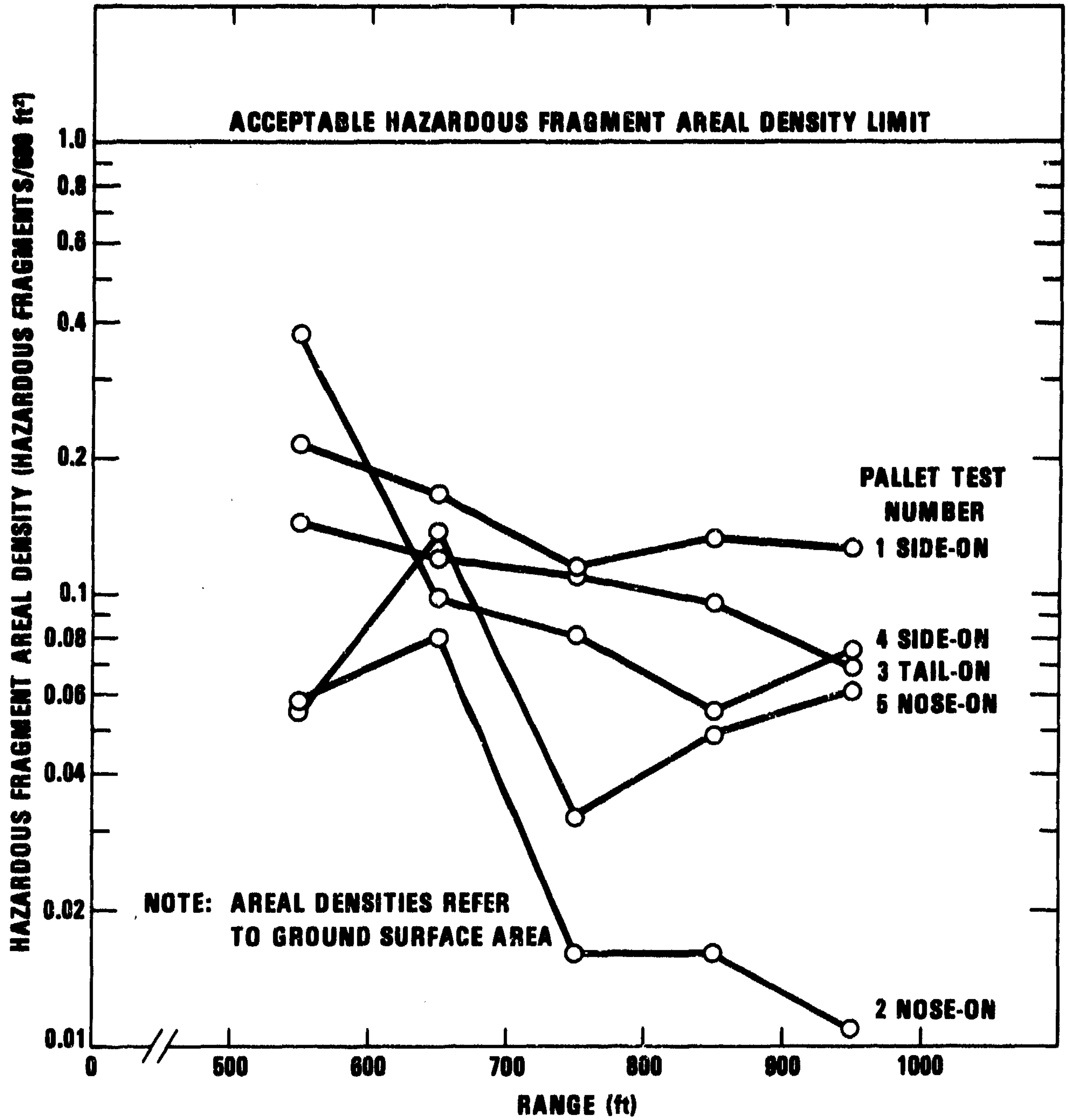


FIGURE 12. HAZARDOUS FRAGMENT AREAL DENSITY VERSUS RANGE FROM MK 82 BOMB PALLET TEST DATA

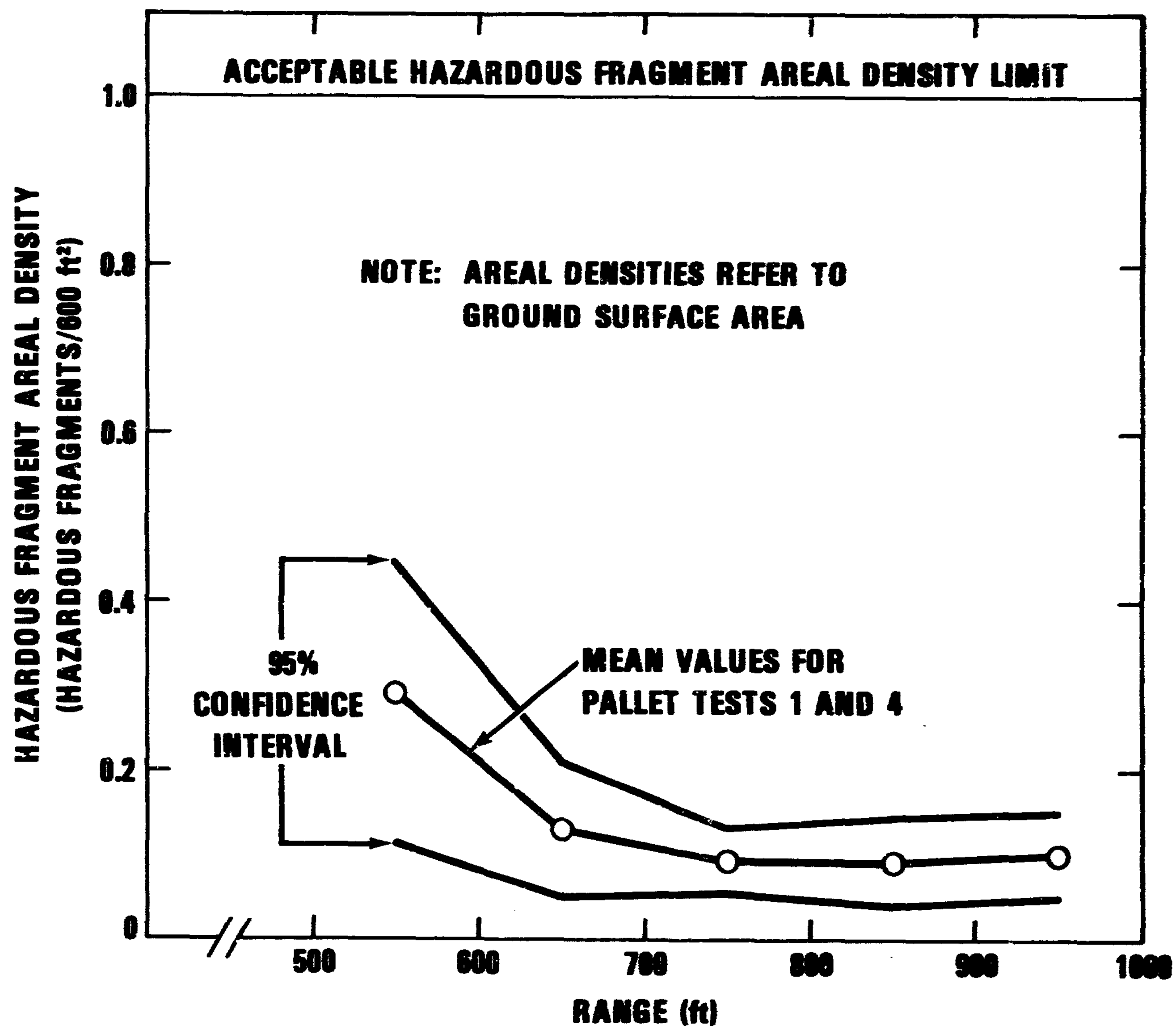


FIGURE 13. HAZARDOUS FRAGMENT AREAL DENSITY VERSUS RANGE FOR MK 82 BOMB PALLET TESTS (SIDE-ON ORIENTATION) WITH 95% CONFIDENCE LIMITS

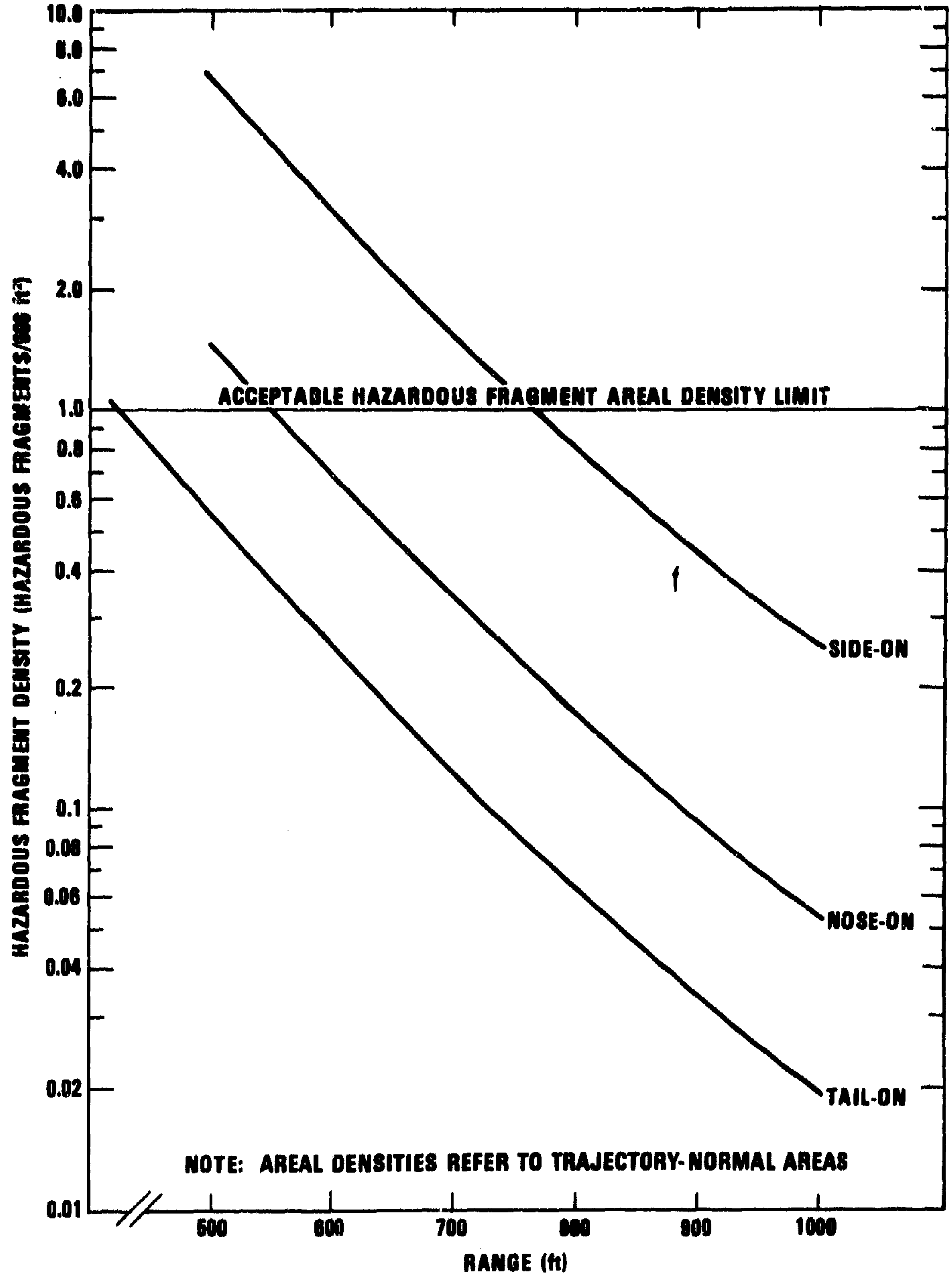


FIGURE 14. HAZARDOUS FRAGMENT AREAL DENSITY VERSUS RANGE FOR MK 82 PALLET – FEN PREDICTIONS

Figure 15 gives comparisons for the single bomb (side-on) test between the data and two separate prediction models, the FEN model and the Fragmentation Hazard model (Reference 11). Once again it should be noted that the areal densities for the data are based on ground surface area whereas the areal densities for both the prediction curves are based on trajectory - normal areas. The Fragmentation Hazard model used fragment trajectory calculations of weapons effectiveness fragment data (close-in fragment collection) from arena tests to determine hazardous fragment areal densities as functions of range. Both low-angle and high-angle trajectories are included in this model. The Fragmentation Hazard model predicts an acceptable hazard fragment range of approximately 650 ft. for the bomb side-spray zone, the FEN model (considering only low angle trajectory fragments) predicts a range of approximately 490 ft. for the bomb side-spray zone. The recovered fragment data results in Figure 15 show quite low levels of hazardous fragments throughout the range from 500 ft. to 1000 ft.

The safety manual for ammunition and explosives ashore, NAVSEA OP 5, (Reference 12) lists the following minimum distances from units of Mk 82 bombs for unprotected personnel in a prone position (Reference 7).

1 bomb --- 670 ft. (This is essentially the same value interpreted in the above paragraph to be approximately 650 ft.)

2 bombs --- 860 ft.

5 bombs --- 1080 ft.

10 bombs --- 1240 ft.

These results are obtained using the methods described in Reference 7 and 11 (The Fragmentation Hazard Model). However, it should be pointed out that the Fragmentation Hazard Model (from which the above numbers were obtained) refers to trajectory-normal area and not horizontal ground surface area (prone target) for computing hazardous fragment areal densities as interpreted for the NAVSEA OP 5 minimum distances.

Table 2 gives a comparison of hazardous fragment areal densities at 500 ft. range between vertical (fiberboard bundles) and horizontal (ground surface) target area for the five pallet tests. These comparisons indicate large differences (ratios from 20 to 66) in presented hazards for vertical targets relative to horizontal targets. This is because the fiberboard bundles capture low-trojectory fragments that could go out as far as 875 ft. range from ground zero (determined by test site geometry) had they not been stopped at the 500 ft. range -- the horizontal areal flux density is much less than the vertical areal flux density for these fragments as indicated by the above comparison.

The recommended acceptable hazard range for fragments is less than 500 ft., as indicated by the data, for horizontal targets. The range would be substantially greater for vertical targets.

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11. D. I. Feinstein, "Fragmentation Hazards to Unprotected Personnel," Final Technical Report IITRI J6176, Contract DAHC-04-69-C-0056, IIT Research

12. Ammunition and Explosives Ashore, Safety Regulations for Handling, Storing, Production, Renovation and Shipping, NAVSEA OP 5 Volume 1, published by the Commander, Naval Sea Systems Command, Change 8 - 1 Sep 1979

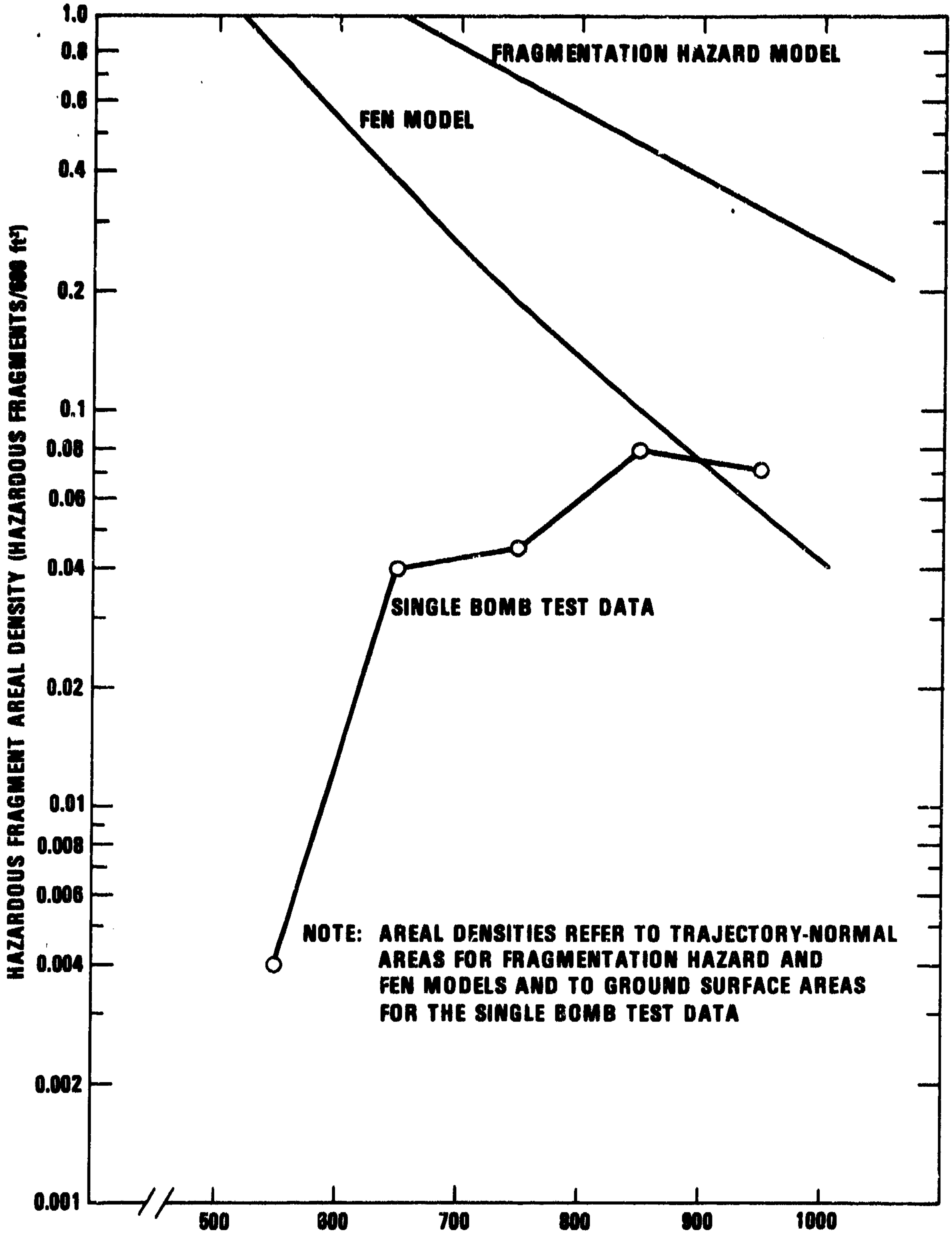

FIGURE 15. COMPARISON OF HAZARDOUS FRAGMENT AREAL DENSITY VERSUS RANGE TEST DATA WITH PREDICTIONS FOR THE MK 82 SINGLE BOMB TEST

TABLE 2
HAZARDOUS FRAGMENT AREAL DENSITIES (#/600 FT^2) AT 500 FT RANGE
FOR MK 82 BOMB PALLET

PALLET TEST	VERTICAL TARGET (FIBERBOARD BUNDLES)	HORIZONTAL TARGET (RECOVERY AREA)	VERTICAL/HORIZONTAL AREAL DENSITY RATIO
1. SIDE-ON	4.3	0.214	20
2. NOSE-ON	1.7	0.058	29
3. TAIL-ON	9.4	0.143	66
4. SIDE-ON	10.2	0.375	27
5. NOSE-ON	1.7	0.056	30

CONCLUDING REMARKS

Tests were performed to determine the acceptable hazard handling arc for a pallet load of Mk 82 bombs (H-6 explosive). The blast criterion (1 psi overpressure) was satisfied at a range of 600 ft., whereas the fragment criterion (1 hazardous fragment/600 ft.^{2} of ground surface area) was satisfied inside the 500 ft. range (inner range limit for fragment recovery). These combined results give an acceptable hazard handling arc of 600 ft. It should be noted here, however, that hazardous fragments do travel beyond the outer range of these tests (1000 ft. from ground zero) but their areal density (ground surface) is less than one per 600 ft.^{2}

Excellent comparisons were obtained between predicted (UTE-NESIP technology base) and measured airblast results. Direct comparisons between the predicted (FEN-NESIP technology base and the Fragmentation Hazard model) and measured hazardous fragment area densities have not yet been performed. The hazardous fragment areal densities for both prediction models are for trajectory-normal area whereas the fragment data are for ground surface area.

Plans are to continue this investigation to the other bombs in the Mk 80 series.

The mention of names of proprietary products in this paper constitutes neither an endorsement nor criticism of these products by the United States Government or by the Naval Surface Weapons Center.

NOTE SNPE/SG/No. 150 of 8.8.1980

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INSPECTION GENERALE
SERVICE SECURITE GENERALE

PAPER PRESENTED
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- - -

THE A.C.A.C.I.A. SYSTEM

By P. FONTAINE, Safety Department Manager

SUMMARY : Description of the organization set-up for pyrotechnical accidents and incidents data management.

Integration of the system with safety studies probability files and with accident prevention organization.

Projections : Computer-aided prevention.

1. INTRODUCTION

379 years ago, in 1601, a Frenchman named ROBIN brought back from what is today the United States East Coast, from the New World, as it was then called, some seedlings of a tree : the LOCUST (Robinia pseudo-acacia). called in French ACACIA. The tree grew in France and is a common species in our areas.

On the strength of this botanical introduction, it can be stated that the S.N.P.E. (Société Nationale des Poudres et Explosifs) selected the word ACACIA as the code name for a pyrotechnical accidents and incidents data collection system, based on the initials of the phrase.

A	Analysis of the
CA	CAuses and of the
C	Consequences of the
I	Incidents and
A	Accidents.

Before describing the organization set-up, it would be convenient to indicate that the S N P E, or Société Nationale des Poudres et Explosifs, upholds the tradition of the late Direction des Poudres, that it employs 6,500 people in 9 different locations and that it manufactures propellants explosives and chemicals not only for national defense but also for civilian applications and for export.

Safety has been and remains the major concern in our industry, whether in regard to our personnel safety or to prevent equipment losses. Such a good safety record has been obtained not only through conventional prevention techniques but as well, since 1972, through the contribution of new methodologies incorporating the safety constraints aggregate in the manufacturing systems.

Concurrently, these techniques have been used to improve the safety of the products and systems we are selling.

For several years, we have been using the three following safety systems analysis techniques :

- Preliminary hazard analysis

- Failure modes and criticality analysis

- Fault trees

Since September 28, 1979, French regulatory laws applying to pyrotechnical factories have been complemented with a very important decree : decree 79846 of September 28, 1979 (copy of it in Annex 1).

In Article 3 of this decree, there is a requirement for a Regulatory Safety Study based on the probability concept. As a matter of fact, the safety distances between buildings definition criteria as well as the decision as to whether or not to keep the personnel close to the explosive chemicals are partly based on the existing probability of becoming the victim of a pyrotechnical accident.

Such techniques require, in various degrees, the availability of data on expected events probability, although they supply valid results even if said probabilities can only be assigned a range of values. In many cases, however, attempts are made to assign numerical values to the probabilities in order to try to measure the obtained safety level and to compare it to the set goals, inasmuch as it has been possible - or desired - to define them in advance.

Concurrently, in order to improve the work injury prevention and to reduce the material damages, we needed to set up a computer-based management organization of all accidents and incidents.

This is what led to the creation of the ACACIA project on January 1st, 1974.

2. DESCRIPTION OF GOALS

The ACACIA project 3 goals are the following ones :

1 - To permit the work injury regulatory processing,

2 - To permit the technical processing of accidents and incidents related to the pyrotechnical or not, activities about which it seems necessary to :

- keep the company's various plants, research centers and subsidiaries informed,
- keep a record for future reference,
- draw comparisons in order to improve accidents prevention and to reduce material damages,
- determine the nature and frequency of events occurring in our shops

3 - To inventory small accidents and incidents poorly followed up so far, even not listed at all, in order to improve accidents prevention while improving database assessments reliability.

The word ACACIA was made from the initial letters of : Analysis of the CAuses and of the Consequences of Incidents and Accidents. Not only does it gives an identity to the project's name, but is also characterizes :

- The name of the printed form : the ACACIA report form used to report accidents and incidents,
- The name of the computer program processing the data,
- The name of the various files utilized, especially those assigned to the assessment of the nature and frequency of the inopportune occurrences encountered in our activities.

3. THE ACACIA REPORT

The aggregate of the ACACIA project rests on one initial procedure : the reporting of a fact significant for safety which may be :

- An accident with bodily injury, with or without any work stoppage,
- An accident without any bodily injury, with or without any material damage, even a hazardous situation without any material damage and without any bodily injury.

These facts are reported by means of a single printed form, the ACACIA Report, put at the disposal of personnel capable of putting the data correctly in writing. As a rule, this means supervisory personnel, but in certain cases, it may be units operators, or foremen, or management personnel (standby duty personnel, control people, etc...) A sample of the report form is given in Annex 2.

The putting in writing of the printed form is easy and deals only with circumstances (top section) and with consequences (middle section). Indeed, it was considered more appropriate not to deal with circumstances and effects in the same document on one hand, and on the other hand with the previous experience or causes, in order to avoid perturbing the description of the facts which does not allow any interpretation by the indication of causes which are nore subjective or subject to hierarchical interferences.

Thus printed form is not specific to pyrotechnical activities, but may just as well be used to report, for instance, a fire in a mixer, an upset cart or a fall in a stairway.

We have approximately 500 report books in service in our plants and research centers, i.e 1 for every twelve persons on the average.

4. REPORT PROCESSING

When the report is transmitted to the Safety department , various procedures are carried out in succession or simultaneously :

- Eventual processing for reporting to Social Security in case of work stoppage,
- Investigation by the hierarchy persons in charge and by the Safety Department
- Eventual investigation and inquiry by the central Department according to enforced procedures,
- Eventual processing by the Safety and Health Committee,
- Computer processing.

In this paper, we will only give details about the procedures carried out from the computer processing; in effect the other ones are conventional ones and are of no particular interest in the ACACIA project.

5. DATA PROCESSING DOCUMENTS

The computer processing of the ACACIA reports is carried out from a coding source permitting the creation of a record similar to a documentary description permitting the monthly or quarterly publication of the various reports utilized by the SNPE services.

From the elementary data coded at the factory level and which you will find in details in Annex 3, the various data processing documents are published and distributed pending the setting up of a conversational search of files organized in database by means of the UNIVAC D M S computer program.

1. Monthly data log. This is the chronological history file of the received reports.

2. Monthly inter-factory list of the pyrotechnical nature accidents and incidents (representing 15 % of the reports). This list is intended to keep the factories informed about all the company incidents and minor accidents in the past month (See Annex 4).

3. Monthly cumulative list for each shop which permits giving for each shop the history file of all received reports. This list is published on micro-fiches each month and on paper every six months.

4. An alphabetical quarterly index of the reports specific to the pyrotechnical activity of the company, obtained through the permutation of the key words characterizing the circumstances, and making it possible to ask later for the communication of more complete reports. This index is published quarterly and, its volume (20,000 references) being taken into account, this is a micro-fiche publication (See Annex 5).

5. The monthly safety chart includes the safety charts for each service and for each factory

These various documents are distributed to the involved services : manufacturing, safety department, processes, documentation, safety research, etc ... in order to help them in the carrying out of their respective tasks.

On the other hand, and independently from the permuted index described above in paragraph 5-4, the reports specific to the company's pyrotechnical activity are stored in the company documentary computer data bank, just as ordinary technical documents would be. This principle will permit, thanks to the selective distribution profiles, keeping each managerial rank person directly and personally informed about the safety events likely to be of interest to him (her). He (she) will then be able to obtain, should he (she) deem it necessary, the detailed report of the precise facts. This principle is the same when dealing with retrospective research.

6. NUMERICAL DATA

As far as numerical data are concerned, we have recorded, since 1974, an average of 1500 reports a year, only 15 % of which are specific to the propellant and explosives activity.

Out of these reports, there are 34 % accidents with work stoppage and 34 % without any work stoppage, 17 % incidents and 15 % hazardous situations.

This record is not satisfactory because the relative number of incidents is too low. Indeed, it is a known fact that the number of incidents is 2 to 3 times higher than the number of accidents. This abnormal accident/incident ratio is the consequence of a deliberate policy in the course of the 3 first years of the system start-up, to privilege the accident in order to impose the system upon all personnel through the "requirement"

of recording accidents and to let the reporting of incidents develop in function of each individual personal factors. This policy yielded good results and we are certain that we are currently tracking all the accidents, even the least serious ones, while allowing the system to become established without any excessive constraints.

We are currently concentrating our effort on the incidents acquisition, as we are encouraged by the evolution of the percentage of recorded incidents, since it is showing an increase from 11 to 30 % from 1974 to 1980. Our 1982 goal is the accidents/incidents parity in the expectation of even a better ratio.

Concurrently to the reports specific to our pyrotechnical activity, which represents only 15 % of the reports, i.e. approximately two hundred a year, we are adding in our files fictitious reports written out from various data about accidents having occurred in other companies in our industry or in industries similar to ours, in France or abroad. We also ran a retrospective on all the data known to us since World War II.
The complete file includes close to 10,000 descriptions, out of which nearly three thousand are of a pyrotechnical nature.

7. UTILIZATION

These files are utilized, either by the safety services in the prevention activity, or by the research and process services to retrieve the useful data, for the study of existing facilities, or for the definition design of new facilities.

They are utilized just as much to acquire knowledge about the events likely to occur in our industries, as to justify the selections made in the safety research, when making quantitative or qualitative assessments.

8. CONCLUSION

The application which was the subject of this paper incorporates in one same organization :

- a Safety prevention activity,
- a Documentary activity,
- a Statistical activity.

Each one of these goals could not have represented by itself a justification for the system's existence; in combining them we did valorize the safety effort which is approved by the company.

The ACACIA project could not have come into being without the will, on the part of our Board of Directors, to privilege safety data and, after more than 6 years of operation, we are witnessing a gradual lessening of the guilt complex concerning the accident and incident concept, and the spontaneous contribution of data by the lower ranks of the personnel who feel proud to participate in the safety effort.

We believe we are progressing toward a true fail-safe set-up. Thank you for your attention.

HEALTH AND SAFETY OF WORKERS

IN PYROTECHNICAL ESTABLISHMENTS

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HEALTH AND SAFETY OF WORKERS
IN PYROTECHNICAL ESTABLISHMENTS

(Decree No. 79.846 of 28 September 1979)

(Edition brought up to date on 28 September 1979

The texts preceding publication of this edition are mentioned in an appended coloured sheet.

In the absence of a sheet, this booklet is up-to-date at the time of purchase.

CONTENTS

Decree No. 79-486 of 28 September 1979

DECREE No. 79.846 of 28 SEPTEMBER 1979

containing official regulations concerning the protection of workers against special risks to which they are subjected in pyrotechnical establishments (Journal Officiel dated 2 October 1979 and amendment in Journal Officiel, NC dated 18 November 1979).

The Prime Minister

Considering the report of the Minister of Defence and the Minister of Labour and Participation,

Considering the Labour Code, and especially Articles L.231-2(2), L.231-3(1) and L.231-3(2);

Considering the Law of 8 April 1938 concerning the appointment of labour delegates for the safety of workers in powder workshops and outbuildings of pyrotechnic establishments, filling shops, cartridge factories depending on the War Administration;

Considering Law No. 70-575 of 3 July 1970 concerning reforms of the regulations governing gunpowders and explosive substances;

Considering Law No. 76-663 of 19 July 1976 concerning installations classified for the protection of the environment;

Considering Decree No. 55-1188 of 3 September 1955 containing public administration regulations governing safety measures in establishments in which explosive substances and pyrotechnic compositions are manufactured, loaded and filled;

Considering Decree No.57-1161 of 17 October 1957 setting the classification of building materials and components in relation to fire hazards in establishments open to the public;

Considering Decree No.62-1454 of 14 November 1962 concerning the protection of workers in establishments which use electrical currents;

Considering the opinion of the Commission on Explosive Substances;

Considering the opinion of the Higher Council on the Prevention of Occupational Hazards;

After consultation with the professional associations of employers and employees concerned,

The Council of State having been heard on the matter,

Decrees the following:

PART 1

GENERALITIES

Field of application

Article 1

The present Decree applies to all establishments or parts of establishments covered by Article L.231-1 of the Labour Code, engaged in the fabrication, filling, cartridge production, storage, packaging, manipulation, analysis, testing and destruction of explosive materials and objects intended for use for the effects of their explosion or for pyrotechnic purposes, without prejudice to the provisions of the Labour Code and those which are applied for enforcement of the above Law of 3 July 1970 and the above Law of 19 July 1976.

It shall not apply to the storage of explosive materials or objects by the establishments which use them for the effects of their explosion or for pyrotechnic purposes.

It shall apply to State establishments depending on the Minister responsible for Defence, subject to the provisions of Article L.611-2 of the Labour Code.

For the enforcement of this Decree to the establishments covered in Article L.611-2 of the Labour Code, the Minister responsible for Defence and the authorities that he appoints for this purpose shall substitute for the Minister responsible for Labour and for the regional and departmental directors of labour and employment, and also, in the event that these establishments do not belong to regional health insurance agencies, for the prevention services of these agencies.

Definitions

Article 2

For the application of this Decree, the terms mentioned above shall have the following meanings:

Explosible material

Substance or mixture of solid or liquid substances which can by themselves, by chemical reaction, liberate gases or heat fluxes in conditions such that damage to surroundings may result.

Explosive material

Explosible material intended for use for the effects of its explosion or for pyrotechnic purposes.

Explosible object

Object containing one or more explosible materials.

Pyrotechnic premises

Premises capable of accommodating explosible materials or objects.

Depot

Installation, building, location or parked vehicle used to store explosible materials and objects.

Pyrotechnic enclosure

Part of an establishment covered in Article 1 including:

The depot or depots used to store the explosible materials and objects intended for use for the effects of their explosion or for pyrotechnic purposes;

Workshops for the fabrication, filling, packaging, analysis and experiments on explosible materials or objects and their service storerooms;

Testing sites and firing ranges;

Destruction areas for pyrotechnic wastes.

Work station

Limited zone located near a machine or installation, in which an employee is required to move to carry out gestures necessary for performing his function.

Work location

Zone situated in a room or in the open air, in which one or more employees are required to move to perform a specific job.

Pyrotechnic risk

Risk incurred by explosible materials or objects during their functional or accidental decomposition.

PART 2

GENERAL SAFETY MEASURES

Article 3

The heads of the establishment, when planning a new fabrication, the use of new explosible materials or objects or new processes, the construction or modification of premises, the creation or modification of an installation, the fitting-out of a work location or station likely to have an effect on the safety of employees or the use of new means or systems of transport in the establishment, shall carry out a safety analysis or shall bring existing safety analyses up-to-date:

> Tending to determine all the possibilities of pyrotechnic accidents and to establish, in each case, the nature and gravity of the risks incurred by the establishment's employees;
>
> Determining the measures to be taken to prevent accidents and to limit their consequences.

The heads of the establishment shall consult the health and safety committee concerning the study, or failing this, the labour delegates, as well as the workers' delegates for safety appointed under the above Law of 8 April 1938 when such exist.

Article 4

The procedures are defined by the head of the establishment in accordance with the conclusions of the safety analysis, and shall be consigned in service instructions.

Article 5

In view of the conclusions of the safety analyses, before implementing the operations which they cover and after consultation with the health and safety committee or, failing this, with the personnel delegates, as well as the workers' delegates for safety if such exist, the head of the establishment shall establish:

General safety regulations;

Regulations concerning each pyrotechnic room;

As required, special regulations specific to each work location or station.

Article 6

The general safety regulations shall define the general rules for access and safety in the pyrotechnic premises. They shall include:

(1) Prohibition to smoke, carry any smoker's articles, and, failing a special permit, the prohibition to carry naked flames, incandescent objects, matches or any other means of creating a flame;

(2) Prohibition of any employee from going to a work location without assignment. Subject to the observation of special safety regulations, this prohibition shall not apply to personnel representatives who are performing the duties which are entrusted to them by the laws and regulations;

(3) Prohibition to proceed to pyrotechnic premises for operations not covered by instructions or regulations in force;

(4) Obligation for the personnel to wear, during working hours, clothing, hats, shoes and other personal safety accessories supplied by the head of the establishment;

(5) Prohibition of personnel to remove explosible materials or objects;

(6) The measures to be observed for driving and parking of vehicles of all types and for the movement of personnel within the pyrotechnic enclosure;

(7) General regulations to be observed in case of fire or explosion.

Article 7

The regulations concerning each pyrotechnic room shall specify the following:

(a) The limitative list of operations authorized in this room and the references to the service instructions which shall be enforced;

(b) The types and maximum quantities of explosible materials or objects and, if necessary, all other dangerous materials which may be found therein and used, as well as their packaging and the locations where they must be placed;

(c) The maximum number of persons, whether or not belonging to the personnel of the establishment, which is authorized to remain permanently or occasionally therein, when it contains explosible materials or objects;

(d) The nature of the wastes produced, the maximum quantity of the wastes which can be stored therein, and their type of packaging;

(e) The procedures to be followed in case of fire, thunderstorm, or lighting or power failure, or in case of any other incident liable to incur a pyrotechnic risk.

Article 8

The instructions specific to each pyrotechnic work location or station shall resume or supplement the provisions relative to this location or station, in the service instructions and regulations mentioned in Article 7 above and shall specify:

The clothing and equipment for individual protection to be worn by the operators;

The limitative list of hand tools and mobile equipment which can be used.

Article 9

Access to premises of the pyrotechnic enclosure shall be prohibited to any person foreign to the establishment with the exception of the accredited representatives of the administrative authority and persons specially authorized by the head of the establishment, these persons having been requested to conform with the safety regulations.

Outside of working hours, the premises containing explosible materials or objects shall be closed by lock and key if not subject to permanent surveillance. The instructions relative to all premises covered by Article 7 above shall designate the person responsible for locking and shall specify the place at which the key must be left outside of working hours.

Article 10

The equipment of work stations where the personnel is exposed to dangers of a pyrotechnic nature and the operating procedure shall be designed so as to prevent precipitation and sudden variations in the work rate when the employee's work is repetitive.

No form of wage or salary shall be such as to encourage the employees assigned to these stations to achieve a work output greater than that resulting from the equipment and the procedure thus defined, with due consideration of pauses which are necessary in work operations requiring sustained attention and, if necessary, the time necessary for work preparation, installation maintenance, and equipment cleaning. The corresponding maximum hourly or daily output produced at a work location or station shall appear in the specific instructions covered in Article 8 above. This level shall not be exceeded in any circumstances.

Consequently, any incentive type of wage or salary shall be prohibited for employees mentioned in the above paragraph.

PART 3

GENERAL CONDITIONS TO BE MET BY BUILDINGS

Distribution of buildings and safe distances

Article 11

Within the pyrotechnic enclosure, separate buildings shall be provided for:

Premises for analysis and testing of explosible materials or objects;

Fabrication of explosible materials;

Filling work, cartridge production, packaging or fabrication of explosible objects;

Storage of explosible materials and objects, with the exception of the storage of the quantities necessary for fabrications under way.

However, filling work, cartridge production, packaging and the fabrication of explosible objects may be carried out in the same buildings as the fabrication of explosible materials, subject to the two following conditions:

The layout of the installations serves to reduce the number of employees exposed to pyrotechnic risk, particularly by avoiding intermediate storage facilities and handling operations;

The safety analysis shows that the pyrotechnic risk to which each employee is subjected individually is not higher than if both categories of installation were located in separate buildings.

Article 12

The pyrotechnic enclosure shall be limited by one or more perimeters. Each perimeter shall take the form of a fence or, failing this, a signpost system clearly visible to any individual entering at any point whatsoever.

Article 13

The buildings and installations exhibiting a characteristic risk of fire or explosion which is not specifically pyrotechnic, such as garages, warehouses for flammable materials not used in the composition of explosive materials, wood depots, carpentry shops, compressed gas depots, shall be excluded from the pyrotechnic enclosure and laid out in such a manner that any incident affecting one of them shall have no effect on the safety conditions in the pyrotechnic enclosure.

Article 14

In the establishments covered by this Decree, the safe distances between two buildings or installations of the pyrotechnic enclosure, and between one of these buildings or installations and a building or installation outside the pyrotechnic enclosure, shall be such that the transmission or propagation of an accident is highly improbable, and that in case of accident sustained by a building or installation, the employees other than those who are found therein shall be subject to a limited risk.

If a building has a blast discharge facade, no other building shall be placed facing this facade unless it is suitably protected.

Ministerial Orders set the requirements applicable for determining the minimum safe distances to be observed, taking account of the type and quantity of explosible materials and objects, the activities performed, and the natural or artificial protection systems which may exist between the buildings or installations.

Type of construction

Article 15

The construction system of the buildings and the types of material employed shall be such that in case of explosion, the risk of the projection of large weights shall be as low as possible.

Measures shall be taken to prevent the fall of large roof or ceiling components of a building normally occupied by employees, in case of an explosion occurring in another building.

Article 16

The buildings shall be designed and built in such a manner that a pyrotechnic accident shall not incur a major risk for individuals other than those who, owing to their activity, cannot be spared from the effects of the accident.

Article 17

The buildings in which pyrotechnic operations are performed shall be of one storey and shall not have any basement.

However, if the operating procedure requires installations with work stations at two or more levels, within a building or outdoors, these work stations shall be laid out in such a manner that the effects of a pyrotechnic accident occurring at one level shall have no serious effect on the work stations located on the other levels, unless the stations located at different levels are not occupied simultaneously when the installations are in service.

This Article shall not apply to work on very tall explosible objects requiring the use of superimposed platforms. In this case, two independent operations shall not be performed simultaneously on the said objects.

Floors, walls, ceilings, gutters and drainage ducts

Article 18

All suitable measures shall be taken, especially by the judicious selection of materials and linings, so that no hazardous reaction shall occur in case of contact, impact or friction with the floors, walls, ceilings or structural frameworks of the premises in which pyrotechnic operations are performed.

Pyrotechnic premises in which explosive material fines are likely to deposit shall not have airtight ceilings whose upper side cannot be inspected and cleaned. The walls and ceilings shall be smooth and shall allow effective cleaning of their entire surface. The drainage gutters and ducts inside or outside the buildings shall be laid out so as to prevent any transmission of explosion or fire, and shall be designed to allow easy maintenance along their entire length. They shall be equipped with an effective retention system placed whenever possible outside the building and immediately adjacent to it. This system shall be easily accessible and frequently cleaned.

Exits and passageways

Article 19

The exits and passageways provided in Article R.233-23 of the Labour Code shall be indicated clearly.

Seats and other equipment shall be designed and laid out so as to avoid hindering the rapid evacuation of personnel.

Article 20

In pyrotechnic premises, each exit and each passageway shall display a width appropriate to the number of persons and the dimensions of the handling machinery expected to pass through.

A minimum of two exits shall be provided for the passage of more than five persons.

No exit or passageway shall be less than 0.80 metre wide.

For a number of persons ranging from three to five, if one exit is available, its width shall be not less than 1.40 metres. For a number of persons ranging from six to ten, the total width of the exits

shall not be less than 1.80 metres, and shall be increased by 0.60 metre per five persons or fraction of five persons in excess of the first ten persons.

These widths are specified after deduction of projections.

Exit doors shall open outwards and shall be opened by a simple push from inside and easily from the outside, when employees are present in the premises. This paragraph shall not apply to warehouses equipped with sliding doors; the doors of these warehouses shall be immobilized in the open position when personnel is present inside.

Article 21

No normal work station incurring a danger of a pyrotechnic nature shall be located at more than 7 metres from an exit or effective shelter. This distance shall be measured by the real path between the work station and the exit. It shall not apply to warehouses nor, if impossible, to premises in which the work is performed on large explosible objects.

Doors, windows and stairways

Article 22

The doors and partitions of pyrotechnic premises shall be built in accordance with the conclusions of the safety analysis discussed in Article 3.

In the absence of special justifications resulting from this analysis:

The doors shall be built of materials of categories MO, M1, M2 or M3, in the sense of the above Decree of 17 October 1957 and the Ministerial Orders issued for its enforcement;

The doors and partitions intended to prevent the propagation of a fire shall exhibit a fire-break degree of at least a quarter of an hour in the sense of the above Decree of 17 October 1957 and the Ministerial Orders issued for its enforcement.

Article 23

In the premises containing explosible materials or objects sensitive to the action of sunlight, the windows, if exposed to the sun:

Shall not display any defect or sharp edge liable to cause the convergence of the sun's days;

Shall also be equipped with blinds kept in good condition, or covered with a lining reducing the sunlight.

Furthermore, in the premises in which impact-sensitive materials are handled, the doors and windows shall be equipped with a suitable device preventing their sudden closure, unless the safety analysis has shown that inflammation is not possible in these conditions.

Article 24

In the buildings of the pyrotechnic enclosure in which personnel is required to remain, the materials used in building the walls, doors and windows, especially the glazing, shall not be such as to produce sharp splinters if they are liable to be broken by internal or external overpressure.

Article 25

Pyrotechnic installations featuring two or more levels covered in Article 17 shall be provided independently with inner stairways, by one or more outdoor stairways, or by equivalent systems, of which the layout and evacuation capacity shall be selected so as to ensure rapid evacuation of the personnel.

Personnel movements

Article 26

The passageways designed for personnel movement inside the pyrotechnic enclosure shall be suitably signposted and marked. They shall be lit if used at night for the normal operation of the establishment.

They shall be separated from the traffic passageways used for the transport of explosible materials and objects not packed in authorized packagings for transport on public roads, unless this is impossible due to the layout of the existing buildings and their access roads. In this case, the transport of these explosible materials or objects shall be interrupted during personnel movement at the start and end of each shift, and at the start and end of each collective pause.

They shall be laid out and protected so as to prevent the personnel required to use them from being exposed to the effects of an explosion

occurring in a workshop; in particular, they shall be separated from blast expansion facades in the conditions set by the Ministerial Orders mentioned in Article 14 of this Decree.

PART 4

GENERAL SAFETY MEASURES

Article 27

If, in consideration of the safety analysis discussed in Article 3 above, the application of the procedures and the strict observation of instructions leave a substantial residual risk of ignition or explosion, the operations incurring this risk shall be performed in the absence of personnel in the danger zone, unless the employees are protected by screens or devices designed for the purpose.

The conditions of application of this Article are defined by the Ministerial Order of the Minister responsible for Labour.

Maintenance and repair work

Article 28

Maintenance and repair operations performed in pyrotechnic premises or in areas adjacent to them shall be subject to the provisions of this Decree. This shall also apply to demolition work affecting old pyrotechnic premises. In particular, the operations mentioned in this paragraph shall be covered by a safety analysis taking account of the risks of accident liable to occur during their execution. This analysis shall be added to the file provided for in Article 87.

If the instructions discussed in Article 5 do not provide for this, special instructions shall define the precautions to be observed during these operations, including, if necessary, the conditions of prior removal of explosible materials or objects and the cleaning of the premises, as well as the checks to be made before putting the installations into service again.

If the explosible materials or objects are not completely eliminated from the premises before the execution of the work, the latter shall be

kept under permanent observation, from the standpoint of pyrotechnic hazards, by a qualified person familiar with the specific risks of the said premises, and employees whose presence is not necessary for the execution of these works shall be evacuated.

Article 29

Workshops and depots of the pyrotechnic enclosure and adjacent areas shall be kept in a permanent state of cleanliness. All dust deposited shall be removed before its accumulation incurs any danger. The instructions shall establish the frequency of these cleaning operations for this purpose.

Raw materials

Article 30

Before being employed, the raw materials or semi-finished products entering into the composition of the explosible materials or objects shall be inspected and carefully rid of any foreign bodies.

Explosible raw materials or semi-finished products or those that incur special risks shall only be introduced in the workshops in which they are employed as the need arises, with the observance of all precautions required to avoid accidental mixtures or spreading liable to produce dangerous reactions.

Article 31

The containers used to transport raw materials and semi-finished products between buildings located inside the pyrotechnic enclosure shall be designed so as to avoid the accidental introduction of foreign bodies.

They shall be made of materials that are easy to clean and are not liable to cause dangerous reactions.

These containers shall be easy to handle and shall be provided, if necessary, with solid handling elements.

Equipment

Article 32

Subject to the application of Article 57 (first and second paragraphs), pyrotechnic premises shall not contain any equipment or object not necessary for the performance of the work therein. The equipment or objects employed shall be suitably cleaned and stored after their use or at the end of the day. The service instructions discussed in Article 4 establish the frequency of maintenance operations for equipment other than daily checks and cleanings.

The equipment and tools shall only be used for the intended purpose.

Article 33

The equipment and tools used in pyrotechnic premises shall be of a nature so as not to give rise to the production of sparks of mechanical or electrical origin, or to dangerous impact or frictional contact, or to any dangerous reaction. They shall not exhibit any exposed parts liable to be raised to a dangerous temperature, in consideration of the types of material employed.

They shall be rugged and shall not include any part liable to be detached or to fall on the explosible materials.

Effective measures shall be taken to prevent the deposit of explosive material fines on components in which they would be subject to friction or dangerous heating, especially inside drive systems. It is prohibited to allow an installation or machine to run which exhibits abnormal friction or temperature rise.

Article 34

The lubrication of the installations shall be designed so that no mixture of lubricant with comburent or explosible materials is capable of causing a reaction which is dangerous for the personnel present in the premises.

Air-conditioning

Article 35

The heating installations of buildings or manufacturing units shall be designed and operated in such a manner that none of their points reaches a dangerous temperature, in view of the nature of the materials employed.

Depending on the types of material used, systems shall be provided, if necessary, to maintain the humidity and temperature of the atmosphere of the pyrotechnic premises at a suitable level.

Article 36

If pyrotechnic premises are heated by radiators, the latter shall be built of a material not subject to change or covered with a suitable coating. If they are liable to be covered with dangerous dust, they shall exhibit smooth walls.

Their layout in relation to the floors, walls and ceilings shall allow easy cleaning of all sides.

They shall also be equipped with devices to prevent objects from being placed in contact with the hot surfaces.

Article 37

If premises liable to contain explosible or flammable fines, gases or vapours are heated by hot air flow, the hot air generators shall be located outside the premises. The air shall be taken from outside the premises, and all recycling is prohibited, unless the air is suitably purified before each recycling by means of a regularly checked and cleaned purification unit.

It is prohibited to carry out hot air production by air flow around a combustion chamber.

The location of the hot air inlets shall be selected so as to avoid any turbulence liable to raise the dust in the premises.

Ventilation

Article 38

If the premises in which the atmosphere is liable to contain explosible material fines are equipped with air exhaust units, the latter shall feature an effective dust-removal system which is regularly checked and cleaned. The frequency of checking and cleaning operations shall be set by the service regulations or instructions discussed in Articles 4 and 5 above.

Without prejudice to the provisions of Articles R.233-14 to R.233-41 of the Labour Code, the following fire-fighting measures shall be observed in the pyrotechnic enclosure:

(a) The approaches to pyrotechnic premises and waste burning zones shall be cleared of weeds and undergrowth; the materials used for week and undergrowth removal shall be such as to avoid causing dangerous reactions with the materials used in the pyrotechnic enclosure. Earth barricades shall be rid of dry weeds and undergrowth;

(b) Explosible material melt tanks, as well as installations in which materials or objects are handled exhibiting a high risk of ignition liable to lead to fire, owing to the operations performed, shall be equipped with an automatic extinguisher system compatible with the types of product to be extinguished. This system shall also be capable of being controlled manually from a location remaining accessible in case a fire breaks out in the installation concerned;

(c) Automatic fire detection systems actuating an instantaneous alarm system shall be installed in the premises in which units liable to cause fires, such as ovens or dryers, operate without permanent surveillance.

However, the provisions discussed in paragraphs (b) and (c) above are not mandatory if, owing to the type or quantity of the materials concerned, the fires considered cannot:

Spread to neighbouring installations;

Trigger explosive reactions;

Cause dangerous projections or the liberation of dangerous quantities of toxic gases or vapours.

Article 40

Materials or objects liable to ignite spontaneously, such as charcoal, powdered or otherwise, wastes, rags and cotton soaked with oil or grease, shall not be introduced into pyrotechnic premises except for immediate use, and shall be removed immediately after use.

PART 5

RISKS OF ELECTRICAL OR ELECTROSTATIC ORIGIN

Article 41

Without prejudice to the provisions of the above Decree of 14 November 1962, electrical installations located in a pyrotechnic enclosure shall meet the requirements of this Part 5.

Article 42

The modes of protection of electrical installations located in premises liable to contain flammable gases or vapours or combustible or explosible fines shall be determined by the head of the establishment in accordance with the conclusions of the safety analysis discussed in Article 3. Furthermore, public administration regulations can establish the modes of protection to be employed or can prohibit the use of electrical equipment in some categories of premises.

In the premises covered in the first paragraph above, electrical installations shall be of Classes VLV or LV defined by the above Decree of 14 November 1962. However, installations of MV or HV classes shall be permissible for uses other than drive force, such as the production of X-rays, subject to a special examination under the safety analysis discussed in Article 3 above.

In pyrotechnic premises exhibiting explosion hazards, the electrical lines shall be provided and protected in accordance with the provisions of Section 5.2.2 of French Standard NF C 15.100 concerning the premises of this type.

Article 43

No overhead line of bare conductors shall be installed in the pyrotechnic enclosure.

Transmission cables shall be buried unless they are effectively protected against impact in the conditions specified in Section 5.2.2 of French Standard NF 15.100.

Gutters intended for water removal shall not be used for the passage of electrical cables.

Article 44

The general distribution board of each electrical installation shall be provided with devices designed to cut off the electric power supply of each building served, separately or in groups, in case of emergency.

The electric power supply of each pyrotechnic area shall be capable of being cut off by actuating a control unit located next to and outside the premises. This unit shall be easily recognizable and readily accessible. If the unit is a remote-control device, it shall meet the requirements set forth in Section 5.3.7.2 of French Standard NF C 15.100.

Article 45

The paths of buried electrical lines shall be marked at the surface by markers or special marks; the markings shall also allow easy identification of the buried cables.

Article 46

In the pyrotechnic premises, no equipment shall remain energized outside of working hours.

However, some units of which the shutdown would compromise normal operation of the establishment, as well as certain safety circuits, may remain energized, unless the service instructions or regulations resulting from Articles 4 or 5 explicitly provide for this.

Article 47

Explosible materials or objects shall be kept at a safe distance from electrical lines and equipment, to prevent any defect in one of these lines or equipment from causing their inflammation or explosion.

Precautions shall be observed to ensure that electrical startup devices cannot operate accidentally or by induction or leakage currents generated by electrical installations, even in case of a defect in these installations, or under the effect of electromagnetic radiation generated by radio or radar transmitters, even if located outside the establishment.

Article 48

Electrical installations shall be designed so that the temperature of their components shall not rise in a dangerous manner, in consideration of the types of explosible material present in the premises. The maximum allowable temperatures shall be determined if necessary by the safety analysis covered in Article 3 above.

Portable and mobile equipment

Article 49

If work operations on objects already loaded with explosible materials and featuring an electrical startup device requiring the use of hand-carried or mobile electrical equipment, or the use of measurement instruments employing electrical currents, the instructions given in Articles 7 and 8 provide for the following in accordance with the safety analysis:

Protection conditions for operators;

Prior checking, frequently renewed during the work, of the insulation of the equipment or instruments, and if necessary, the grounding of their earths.

Article 50

Soldering irons may be heated electrically if they are automatically separated from their power supply source during use, or if the safety analysis has shown that maintenance of electrical power supply does not incur any danger.

Supplementary equipotentiality

Article 51

In pyrotechnic premises, unless the safety analysis has shown that such a layout does not reduce the risks of the generation of dangerous sparks, all the earths and all conductive elements shall be interconnected by an additional equipotential connection. This connection shall be executed in accordance with the provisions of Sections 4.1.3.5.2 to 4.1.3.5.4 of French Standard NF C 15.100. Instructions issued by the head of the establishment shall set the frequency of checking of the equipotential connection.

Earth connections and lightning conductors

Article 52

The general earthing connection shall be executed by a belt in a trench surrounding the buildings.

The lightning conductor downleads attached to pyrotechnic buildings shall be connected directly to this earth belt, but at each of the connections, a special so-called "crow's foot" earthing device shall be provided.

These domains shall be kept at a safe distance from the conductive elements of the building and from the earths and other safety conductors, in order to minimize the risk of sparks between the downleads and the other conductive parts.

Precautions against static electricity

Article 53

In the handling of explosible materials or objects known to be sensitive to static electricity discharges in the conditions of these handling operations, the latter should be organized to avoid the effects of these discharges, either by using devices designed to ensure the dispersal of the electrical charges liable to be formed, or by any other means of equivalent effectiveness.

In the case discussed in the foregoing paragraph, the clothing, shoes and other equipment carried by employees shall be such as to prevent the dangerous accumulation of electrostatic charges.

Conductors associated with static earthing systems shall be connected directly to the main earthing conductor of the electrical installation.

PART 6

MEASURES FOR INDIVIDUAL PROTECTION, EMERGENCY MEASURES

Article 54

In the event that personnel safety cannot be guaranteed completely by

arrangements in the premises, installations and work stations, appropriate individual safety equipment such as masks, gloves, shoes and goggles shall be made available to the employees.

The head of the establishment is required to take all necessary measures to ensure that this equipment is effectively used and suitably maintained. The equipment must be checked and cleaned before assignment to a new owner.

Article 55

The head of the establishment shall provide every employee working in the pyrotechnic enclosure with suitable work clothing appropriate to the risks and type of work to be performed.

The supply, maintenance and cleaning of this clothing is the employer's responsibility.

Soiled work clothing shall be replaced by clean articles as often as required.

If this clothing incurs a special risk of inflammation owing to the type of material with which it is impregnated, the head of the establishment shall make sure that their cleaning inside or outside the establishment is carried out with all necessary precautions.

Article 56

In premises where the operations performed are liable to give rise to the production of dust incurring risks for the personnel, it is prohibited to allow personnel to enter without protecting their hair by suitable headgear.

Article 57

If the work rooms are distant from the dressing room, clothing pegs in adequate numbers shall be installed in these rooms or in adjacent rooms. These pegs are intended exclusively for the clothing used by the personnel for protection against inclement weather during circulation within the establishment.

If the materials present in the work premises are liable to impregnate this clothing or to impart to it a special risk of inflammation, pegs shall be installed in an adjacent room or in a special cupboard, and the clothing shall be supplied and maintained by the employer.

If soiled work clothing of some employees exhibit a danger acknowledged by the safety analysis, the dressing rooms assigned to these employees shall have two distinct rooms, separated by a shower and wash room, with one room reserved for cupboards intended for town clothing, and a second for cupboards intended for work clothing.

Monitoring of the atmosphere

Article 58

Periodic checks shall be made of the atmosphere in the work stations incurring the risk of the generation of dust, gas or toxic vapours, which are flammable or explosible. The frequency of inspection shall be set by service rules or instructions specified in Articles 4 and 5, in accordance with the conclusions of the safety analysis.

Emergency facilities

Article 59

A special study shall specify the type and scope of all accidents which are foreseeable.

The emergency measures necessary shall be defined and implemented by the head of the establishment in accordance with the results of this study and any external means which may be employed. These measures shall be reported to the departmental Director of Labour and Employment, and the Health and Safety Committee.

Article 60

The work must be organized in such a manner that in case of accident, the alarm can be given and aid implemented without delay at all times, round the clock.

The aid station specified by Article D.241-28 of the Labour Code shall be equipped with the health materials required in accordance with the risks and number of personnel, and shall also contain first aid materials for burns. In addition, at least one vehicle must be permanently capable of satisfactorily ensuring the rapid removal of a burn victim to the medical care unit with which the head of the establishment has concluded an agreement designed to guarantee the acceptance of an employee suffering from burns, at any time.

Article 61

In workshops in which the personnel is exposed to the risk of burns by flame, devices designed to extinguish flames on employees shall be placed near each workshop, including immersion tanks, strong showers, and suitable blankets. The type of device employed shall be determined by the head of the establishment in accordance with the risks specific to each workshop, and based on the opinion of the establishment's doctor.

In workshops incurring a risk of chemical burns, a shower must be provided along the workshop exit path. Other devices appropriate to the risks specific to each workshop may replace or supplement the shower, with the agreement of the doctor.

Medical observation

Article 62

As required, Ministerial Orders establish the technical instructions to be followed by occupational doctors to ensure the medical observation of employees exposed to the effects of certain toxic or unhealthy materials used in the establishments governed by this Decree, and, if necessary, to order additional examinations under the employer's responsibility.

PART 7

TRANSPORT WITHIN THE ESTABLISHMENT. STORAGE

Transport of explosible materials and objects

Article 63

The installations, equipment and machines intended to transport explosible objects or materials shall be designed and used so as to prevent the fall, dispersion, and any dangerous contamination of these objects or materials.

Article 64

The equipment designed to ensure continuous transport of explosible materials or objects between two work locations shall be designed and used so as to avoid any transmission of an explosion or the rapid propagation of a fire affecting the materials transported along the equipment.

Article 65

Ducts intended to transport explosible materials between two work locations in liquid form, or in the form of solids in suspension, shall have a diameter smaller than the critical detonation diameter determined by the safety analysis. However, systems of equivalent effectiveness which oppose the transmission of the detonation may be employed.

Pumps used to transport these materials shall be of a model appropriate to their type and to the risks which they are liable to incur, as shown by the results of the safety analysis.

Article 66

Conveyor belts shall withstand flame and the action of the chemicals employed.

Article 67

The means of protection of the motors of equipment and machines intended for batch transport of explosible materials or objects within the establishment shall be determined by the head of the establishment in accordance with the conclusions of the safety analysis specified in Article 3. Furthermore, public administration regulations may define the means of protection to be used and may prohibit the use of certain types of motor.

Article 68

The equipment and machines discussed in the foregoing Article shall be restricted to the traffic lanes and areas provided for the purpose. The latter shall be suitably signposted and illuminated, and shall have a level travel surface, free of holes, projections or other obstacles.

They shall also be prepared and arranged so as to avoid any transmission of an explosion of the load transported to explosible materials or

objects located in buildings occupied by employees other than those of departure or arrival.

The equipment and machines shall be designed and the loads fastened so that the driver's field of view is adequate.

Article 69

To avoid any confusion between the different models of handling machinery used in the pyrotechnic enclosure, they must be signposted in a durable and perfectly visible manner, according to the sector(s) in which they are authorized to circulate.

Storage of explosible materials and objects

Article 70

Depots, cabinets, bins and vehicles for storage shall not contain bare explosible materials, except, as required, for blocks of solid propellant acknowledged to be insensitive to impact and friction by the safety analysis discussed in Article 3. Packings shall be adapted to the stresses to which they are subjected during handling and on account of stacking. They shall not allow the dispersion of explosible materials. Damaged packings shall be removed immediately from the depot and the latter carefully cleaned of any materials which may have spread. Warehouse management shall prevent any accidental mixture of materials liable to give rise to dangerous reactions.

A single depot shall not contain explosible materials or objects falling within different eompatibility groups. These groups are defined by the Order of the Minister responsible for Labour.

Stored explosible materials in which ageing compromises chemical stability shall be inspected at a frequency established by instructions discussed in Article 5, and shall be removed and destroyed if the result of this inspection is unfavourable. The inspection results shall be entered in a register bearing the name and rank of the person assigned responsibility for it by the head of the establishment.

Article 71

A depot, cabinet or bin shall only be used to store explosible materials or objects for which it is intended, and shall not contain any accumulation of easily flammable materials.

Within a depot, a panel shall indicate the type and maximum quantities of the materials or objects stored therein, on each compartment.

Article 72

The storage rooms and passages providing access to them shall be dimensioned and laid out to facilitate rapid evacuation of personnel, while minimizing the risks of impact due to the circulation of materials handling machinery.

Fill materials used to build buried depots shall not be subject to spontaneous heating.

Article 73

Packaging materials liable to be in contact with explosible materials shall not be capable of causing friction or dangerous reactions with these materials.

Article 74

Packages containing explosible materials and objects shall be stacked in a stable manner. If handling is carried out by hand, the package bottoms shall not be more than 1.60 metres above the floor. When suitable mechanical means are employed, the stacks shall not reach a height exceeding 3 metres. The provisions of this paragraph do not apply to storage in fixed bins, provided that the operators can place the loads in a suitable position at any time, without any risk of impact or handling error due to imperfect visibility.

Packages containing explosible materials or objects shall not be thrown or dragged.

The packages shall not be opened in storage depots.

Packages opened outside a depot and containing a residue of explosible materials or objects may be returned to the depot after satisfactory inspection and closure.

PART 8

TREATMENT OF WASTES AND EFFLUENTS

Article 75

Explosible materials which spread accidentally outside the units or containers shall be neutralized immediately on the spot by procedures designated by a safety analysis, or shall be collected for removal and destruction.

Wastes consisting of different types of explosible material shall be collected separately, unless the safety analysis discussed in Article 3 has indicated the possibility of combining certain wastes. They shall be placed in containers which are suitable, closed, carefully differentiated and compatible with the type of waste.

Article 76

Containers intended for wastes and placed in workshops shall be of limited capacity. They shall be removed frequently to units of the same type, placed outside the workshop, which may be of larger capacity and may be emptied at longer intervals.

Service instructions and regulations discussed in Article 5 of this Decree establish the procedures for the removal of wastes and marking of the various containers, in order to minimize the amounts of waste which may be deposited and to avoid any combination of materials which is liable to be dangerous

Article 77

Waste destruction operations by calcining, firing or incineration shall be carried out in the sector assigned to destruction, and with specially designed equipment.

The instructions and regulations discussed in Articles 4 and 5 of this Decree determine the procedure and personnel protection measures. They establish the maximum amount of wastes which may be treated simultaneously.

Destruction areas for pyrotechnic wastes may be located within proving grounds and firing ranges.

the capabilities and are equipped with the necessary means to ensure the strict application of service instructions and safety regulations.

Article 82

The performance of pyrotechnic operations shall only be entrusted to personnel authorized for the purpose by the head of the establishment, who has previously confirmed that this individual has the capabilities necessary to perform these functions.

Article 83

On employment or assignment as discussed in Article 82, each employee shall receive one copy of this Decree and one copy of the general instructions discussed in Article 6. The general instructions shall be posted at the entrance to the establishment on the personnel passageway and also in the dressing room.

One copy of the service instructions concerning each room, discussed in Article 4, shall remain permanently in a file made available to the employees who are assigned to this room, and shall be within immediate reach.

The regulations discussed in Articles 7 and 8 shall be displayed, depending on each specific case, within the work room or near the work station or location. However, in case of complex operations, posting may be limited to extracts of these instructions, which shall then appear in full in the file discussed in the previous paragraph.

Article 84

Practical training in safety matters discussed in Article L.231-3-1, paragraph 1, of the Labour Code, shall include the detailed explanation of regulations and instructions established in enforcement of Articles 4 and 5 of this Decree.

In enforcement of Article L.231-3-1, fourth paragraph, it shall be supplemented by permanent training of the personnel assigned to pyrotechnic operations, including employees discussed in Article 81. This training shall be provided during normal working hours. It shall depend on the functions and competence of each employee, and is intended to maintain and improve the knowledge of those concerned in the area of pyrotechnic risks and their prevention. In particular, the head of the establishment shall organize training sessions for employees. Each employee shall be required to attend one of these sessions at least once every quarter, during which the instructions and

Article 78

Unusable explosible materials, such as scrap, material resulting from cleaning operations, as well as used cleaning objects, shall be packed, removed and destroyed in the same conditions as the wastes mentioned in Article 75 above.

Article 79

Priming devices and cartridges or explosible objects fitted with their ignition device shall not be mixed with other wastes of explosible materials, and shall be destroyed separately.

Article 80

Production waste waters liable to contain explosible or flammable materials shall be treated so as to prevent any dangerous accumulation.

Tanks or ditches containing the waste waters shall be readily accessible, easy to inspect, easy to clean and protected in such a manner that no material or object can fall therein liable to create a risk in the presence of the waste waters.

During effluent treatment, waste waters of different types shall not be mixed unless the safety analysis discussed in Article 3 above has confirmed that this operation incurs no increase in pyrotechnic risks.

PART 9

STAFF, TRAINING AND INFORMATION

Article 81

The heads of the establishment shall make sure that the personnel assigned to management of operations, such as departmental heads, engineers, shop foremen, laboratory and worksite managers, possess the proficiency and authority necessary to organize and direct the activities for which they are responsible within the pyrotechnic enclosure, in accordance with this Decree and the rules of the Art.

They shall also make sure that subordinates assigned by the above personnel to carry out or supervise pyrotechnic operations possess

regulations likely to concern him are reviewed and discussed, and suggestions concerning improvements to safety shall be examined.

PART 10

MISCELLANEOUS PROVISIONS

Measures of an administrative nature

Article 85

In case of the creation of a new establishment, new fabrication, the use of new explosible objects or materials or new processes, the construction or significant alteration of a pyrotechnic room or installation, the use of new means of transport of explosible objects or materials, the safety analysis discussed in Article 3, to which is added the report of consultation of the Health and Safety Committee, shall be submitted for prior approval to the departmental Director of Labour and Employment, who consults the Director of Technical Inspection of Armaments for Powders and Explosives. The departmental Director shall make his decision known to the head of the establishment within three months from receipt of the approval request. He may however, by decision with justification, set a new deadline if required by examination of the file.

He may also, by justified decision, request the head of the establishment to carry out or to have carried out, at the cost of the company, and by a competent organization, additional tests necessary for the assessment of potential risks and of the effectiveness of the planned means of protection.

The three-month period shall begin again from the date on which the departmental Director has gained familiarity with the results of these tests.

In the absence of an answer from the departmental Director within the deadlines set, the head of the establishment may, in conditions resulting from the safety analysis, implement the planned operations. Should he dispute one of the decisions taken by the departmental Director in application of this Article, he shall approach the Minister responsible for Labour, for decision.

Article 86

For the enforcement of this Decree in the establishments mentioned in Article 1, first paragraph, the labour inspectorate shall receive assistance from the technical inspectorate of armaments for powders and explosives of the Ministry of Defence.

Article 87

The heads of the establishment shall keep a safety file available for the labour inspectorate, the technical inspectorate of armaments for powders and explosives, the inspector of occupational and labour medicine, the prevention department of the regional Health Insurance Agency, the Health and Safety Committee, or, failing this, personnel delegates and, if necessary, workers' safety delegates. These individuals shall be kept to secrecy, concerning production processes, in the conditions specified by the regulations in force, and shall only have the right to use the information at their disposal for the performance of their functions.

Article 88

The safety file discussed in Article 87 shall be kept permanently up-to-date and shall contain all new information drawn from incidents and any observation or information likely to concern pyrotechnic safety. It shall include:

Brief description of the production process, accompanied by flow charts and diagrams necessary for its understanding;

The safety analyses discussed in Article 3, to which are added the results of tests which were necessary for preparing them;

Service instructions and regulations established in application of the provisions of Articles 4 to 8;

Reports of accidents and incidents of a pyrotechnic character;

Results of atmospheric monitoring operations specified by this Decree.

Article 89

On justified request by the head of the establishment, the regional Director of Labour and Employment may, by decision taken on the basis of the report of the Inspector of Labour, after receiving the opinion

of the Technical Inspectorate of Armaments for Powders and Explosives, grant, for one or more predetermined installations, and in the conditions which he establishes, a derogation to the following provisions of this Decree:

Article 11 Separation of activities within the pyrotechnic enclosure.

Article 13 Exclusion of non-pyrotechnic installations from the pyrotechnic enclosure.

Article 16 Absence of major risk in a work location in case of accident occurring in a neighbouring work location.

Article 17 Prohibition of buildings with two storeys or basement, or work on two or more levels.

Article 21 Distance of work stations from exits or shelters.

The request shall indicate the compensatory measures planned by the head of the establishment. It shall be accompanied by the opinion of the Health and Safety Committee or, failing this, personnel delegates and, if necessary, the workers' delegate for safety.

The decision of the regional Director of Labour and Employment shall be communicated to the Health and Safety Committee by the head of the establishment. One copy of this decision shall be sent by the regional Director to the Minister responsible for Labour.

The Minister responsible for Labour may, in the same conditions, grant a derogation to some provisions of this Decree, other than those mentioned in the first paragraph above.

Article 90

The Minister responsible for Labour may grant derogations of a general scope to certain technical provisions of this Decree, by Orders issued after receiving the opinion of the Commission on Explosible Substances and the Higher Council for the Prevention of Occupational Hazards. These Orders shall set the compensatory safety measures to which these derogations are subordinated, as well as the period for which they are granted, and which shall not exceed three years.

Entry into force

Article 91

Subject to the temporary provisions defined in Articles 92 and 93, the provisions of this Decree shall enter into force one year after its publication in the Journal Official. The Decree of 3 September 1955 mentioned above shall cease to be enforceable on the same date and subject to the same reservations.

Article 92

I

The provisions mentioned below shall not apply to installations existing on the date of entry into force of this Decree, provided that a safety analysis carried out in the conditions specified in Article 3 has shown that maintenance of these installations in their present condition does not incur any significant risk:

Article 11 Separation of activities within the pyrotechnic enclosure.

Article 14 Observance of safe distances defined by Ministerial Order.

Article 15 (second paragraph) Prevention of the fall of roofing components.

Article 17 Prohibition of buildings with two storeys or basements, or work on two or more levels.

Article 22 Fire behaviour and degree of resistance to fire of building materials and components used in the construction of pyrotechnic premises.

Article 23 (second paragraph) Protection against the sudden closure of doors and windows.

Article 24 Use of materials not producing cutting fragments.

Article 37 (first paragraph) Provisions concerning hot air heating.

Article 45 Marking of buried cables.

Article 52 Belt in trench and connection of lightning protection downleads if the application of this Article requires action on the foundations or structural work of the buildings.

Article 68 (second paragraph) Prevention of the transmission of an explosion from a transport machine to a building occupied by employees.

However, the possibility of maintaining, in their present condition, installations not complying with Articles 11, 14, 17 and 37 (first paragraph) is restricted to those of these installations which satisfy the provisions of Articles 2, 3 (first paragraph), 3 (third paragraph) and 9 of Decree No. 55-1188 of 3 September 1955.

These temporary provisions shall cease to take effect for buildings or installations concerned which undergo significant modification. This shall also apply if the building components covered by this Article shall be replaced.

II

The following provisions shall apply to installations existing on the date of entry into force of this Decree:

(a) The instructions established in application of Articles 21 and 22 of the Decree of 3 September 1955 mentioned above may be maintained in force by the head of the establishment if the installations and fabrications concerned have not be modified significantly since these instructions were established, and if they are not contrary to the provisions of this Decree. If these conditions are not satisfied, the existing instructions and regulations shall be replaced by new instructions established in accordance with Article 5 above, after the carrying out of a safety analysis;

(b) The distance of 7 metres mentioned in Article 21 is raised to 10 metres;

(c) Notwithstanding the provisions of Article 43, first paragraph, overhead lines of bare conductors existing on the date of entry into force of this Decree may be kept in the portions which do not pass above pyrotechnic premises or traffic lanes along which explosible materials or objects are transported. They may also be kept above these traffic lanes if they are equipped with effective devices preventing their fall.

Article 93

With respect to installations existing at the date of entry into force of this Decree, the provisions listed below shall only be applicable on exploration of the deadlines set below, starting from this date of entry into force:

Article 13 Exclusion of non-pyrotechnic installations from the pyrotechnic enclosure: 5 years

Article 16 Non-transmission of an accident from one work location to another: 5 years

Article 18 Regulations concerning floors, walls, ceilings, trenches and removal ducts: 5 years

Article 20 (fourth paragraph) Width of exits: 1 year

Article 25 Outdoor stairways: 2 years

Article 26 (first paragraph) Lighting of passageways: 1 year

Article 26 (third paragraph) Distance of traffic lanes from expansion walls: 5 years

Article 27 Absence of personnel in certain zones: 5 years

Article 39 (paragraph (c)) Automatic fire detectors: 5 years

Article 42 (third paragraph) Electrical lines conforming with Section 5.2.2. of French Standard NF C 15.100: 5 years

Article 43 Regulations concerning overhead lines of bare conductors: 3 years

Article 44 Regulations concerning the protection of electrical installations: 5 years

Article 51 Additional equipotential connection: 5 years

Article 57 (second paragraph) Separation of dressing rooms: 3 years

Article 64 Regulations concerning equipment intended for continuous transport of explosible materials or objects: 3 years

Article 74 Limitation of stack heights when mechanical methods are employed: 5 years

Article 94

The Minister of Defence and the Minister of Labour and Participation shall be charged, each in his own area, with the application of the present Decree, which shall be published in the Journal Officiel of the French Republic.

Paris, 28 September 1979.

Raymond Barre.

By the Prime Minister:

The Minister of Labour and Participation,
Robert Boulin.

The Minister of Defence,
Yvon Bourges.

S.N.P.E.
USINE DE :

DECLARATION ACACIA

Date des faits :	Heure	Jour - Semaine	Temps écoulé depuis reprise	Bâtiment :	Cellule local :	Nº Poste :	Service responsable du lieu : →

OPÉRATION : ______ Nº de GAMME : Annexe 2

DESCRIPTION DES CIRCONSTANCES : ______

VICTIME (une déclaration par victime)

NOM & PRÉNOMS : ______

PROFESSION : ______ MAT. : ______

HORAIRE : ______ ANCIENNETÉ DANS LE POSTE : ______

SERVICE DE RATTACHEMENT : ______

TÉMOINS : 1/ ______ 2/ ______

DÉCLARATION RÉDIGÉE PAR : ______

QUALITÉ DU RÉDACTEUR : ______

DATE : ______ VISA : ______

DÉGATS MATERIELS / SITUATION DANGEREUSE

OBSERVATIONS DU RÉDACTEUR : ______

A REMPLIR PAR L'INFIRMERIE

TRIPTYQUE*: OUI ☐ NON ☐

SEXE : ______ AGE : ______

NATURE LÉSION : ______

SIEGE LÉSION : ______

OBSERVATIONS ET SUITES DONNÉES : ______

DATE : ______ SIGNATAIRE : ______

VISA : ______

DATE RÉCEPTION SERVICE SÉCURITÉ :

Nº ACACIA

OBSERVATIONS SÉCURITÉ : ______

1583

ANNEXE 3.

SAMPLE OF DOCUMENTARY DESCRIPTION.

Code number	Date	With or without injury	Pyrotechnical or not	Dept.	Shop number
N° de la Déclaration.	Date	Nature de l'accident (AA=avec Arrêt)	Caractère	Service	Bâtiment

02 75 0075 * 28.03.75 * ACCIDENT AA * AUTRES * FA/PB * PAF 234

EN NETTOYANT LE DESSOUS D'UN POT DE PRESSE EN POSITION HAUTE
UN OUVRIER A EU LE POIGNET GAUCHE COINCE ENTRE LE POT
DE PRESSE ET LE DESSUS DE LA PLAQUE FILTRE LA VANNE INSUFFI-
SAMMENT FERMEE LAISSAIT CE POT DE PRESSE DESCENDRE IMPERCEPTI-
BLEMENT
CONTUSION PAR ECRASEMENT FACE DORSALE POIGNET GAUCHE

POUDRES PROPULSIVES/PRESSES A FILER/NETTOYAGE/
CIRCUIT HYDRAULIQUE/DISPOSITIF DE SECURITE.

Circumstances Circonstances

Conséquences Humaines et Matérielles → Conséquences

Mots Clefs. → Key Words

SNPE-ACACIA 34. -6

LISTE DES ACACIAS PAR NATURE ET TYPE LE 26/02/76

PYROTECHNIQUE ACCIDENT

ETABLISSEMENT 02 BERGERAC

*02 76 0002 * 08 C1 76 * ACCIDENT AA * PYROTECHNIQUE * PEU-GRAVE * FA/NC * BAT77 * *
AU COURS DU DECHARGEMENT DE L'ESSOREUSE 13 UNE PRISE EN FEU AVEC DEGAGEMENT DE VAPEURS NITREUSES A PROVOQUE UNE LEGERE
INTOXICATION DE L'OUVRIER PRESENT
INTOXICATION VAPEURS NITREUSES/25 KG PRODUIT PERDUS
PRISE EN FEU/DECHARGEMENT/ESSOREUSE ROBATEL BAT77/OUVRIER LEGEMENT INTOXIQUE/VAPEURS NITREUSES/

*C2 76 0010 * 20 C1 76 * ACCIDENT AA * PYROTECHNIQUE * PEU-GRAVE * FA/NC * BAT66 * *
PRISE EN FEU A LA DESHYDRATATION CONTINUE ESSOREUSE KRAUSS MAFFEI NO 20 OPERATION DE CANE20 ISOPROPYLIQUE A 35% UN OUVR
IER A EU UN COUP DE CHALEUR AU VISAGE ET AUX MAINS
COUP DE CHALEUR AU VISAGE ET AUX MAINS/PAS DE DEGAT/ MATERIELS/50KG PRODUIT EN SEC PERDUS
PRISE EN FEU/ESSOREUSE KM NO20/DESHYDRATATION ISOPROPYLIQUE/CANE20

*C2 76 0013 * 22 C1 76 * ACCIDENT AA * PYROTECHNIQUE * PEU-GRAVE * FA/NC * EX-CEN * *
LEGERES BRULURES AU VISAGE ET A LA MAIN GAUCHE AU COURS D'UNEXERCICE SUR FEU REEL.UNE SAUTE DE VENT EST L'ORIGINE DE CET
INCIDENT
LEGERES BRULURES AU VISAGE ET AUX MAINS
LEGERES BRULURES/VISAGE ET MAIN GAUCHE/EXERCICE FEU REEL/SAUTE DE VENT DEVIANT LES FLAMMES

PYROTECHNIQUE INCIDENT

ETABLISSEMENT 02 BERGERAC

*C 6 0007 * 19 C1 76 * INCIDENT. * PYROTECHNIQUE * GRAVE * FA/PB * PAF333 * *
AU DECLENCHEMENT DES VERINS D'APPUI UNE DETONATION A ETE PERCUE AU NIVEAU DES PLAQUES CRIBLES SUIVIE D'UNE ODEUR DE POU-
DRE BRULEE
PAS DE VICTIME/PAS DE DEGAT/
DETONATION/NIVEAU PLAQUES CRIBLES/PAF333/

*C2 76 0018 * 30 C1 76 * INCIDENT * PYROTECHNIQUE * GRAVE * FA/PB * PAF334 *
EN FIN DE FILAGE UNE DEFLAGRATION EN PROVENANCE DES PLAQUES CRIBLES EST PERCUE UN OUVRIER ASSURE AVOIR VU UNE FLAMME SOR
TIR ENTRE LA PLAQUE SUPERIEURE ET LA BASE DU POT
PAS DE VICTIME/PAS DE DEGATS/
DEFLAGRATION/PAF334/FIN DE FILAGE/AUCUN DEGAT

ETABLISSEMENT 03 C.R.B.

*C3 76 0006 * 13 C1 76 * INCIDENT * PYROTECHNIQUE * GRAVE * TD/S * 1228Z * DOC *
DEFLAGRATION DE PRODUITS PYROTECHNIQUES AU COURS DE LEUR DESTRUCTION PAR BRULAGE EN CHAMBRE DE TIR
CASEMATE DE TIR GRILLE DE METAL DEPLOYE A REPARER FILET DE PROTECTION A REMPLACER LIT DE CAILLOUX A REMETTRE EN PLACE SU
R L'ENCEINTE DE TIR
DEFLAGRATION/BRULAGE/DESTRUCTION DE PRODUITS PYROTECHNIQUES/ENCEINTE FERMEE/MELANGE HETEROGENE/

ETABLISSEMENT 06 PONT-DE-BUIS

*C6 76 0003 * 06 C1 76 * INCIDENT * PYROTECHNIQUE * TRES GRAVE * TE * 138 * *
PRISE EN FEU AU COURS DE SOUDURE AU CHALUMEAU SUR UN TUYAU DU SYSTEME D'INONDATION.CE TUYAU TRAVERSAIT UN MUR IMPREGNE D
E POUSSIERES DE COTON POUDRE

ACCUMULATEUR ELECTRIQUE 05 08/06/78

** *02 59 0006 * 11 12 59 A H * * INCIDENT * AUTRES * MANUTE * X * DIC *
EXPLOSION DE LA BATTERIE D UN CHARIOT FENWICK,APRES SA MISE EN CHARGE.CONSECUTIVE A UNE ACCUMULATION D HYDROGENE ET A UN COURT CIRCUIT OU AU CONTACT DES BORNES SUR LE COUVERCLE DU CAISSON DE LA BATTERIE.
UNE BATTERIE D ACCUMULATEURS DETRUITE.
EXPLOSION/ACCUMULATEUR ELECTRIQUE/VEHICULE TRANSPORT/CHARIOT/MANUTENTION

** *10 61 0010 * 24 10 61 A H * * INCIDENT * AUTRES * SD * CHARIO * DIC *
EXPLOSION PENDANT LA CHARGE D ACCUMULATEURS D UN CHARIOT ELECTRIQUE.LA CAPACITE DU CHARIOT EST DE 486 AH.CELLE DU CHARGEUR DE 45 A MAXIMUM.APRES 7 H DE CHARGE L EXPLOSION S EST PRODUITE ALORS QUE LA SATURATION N ETAIT PAS ATTEINTE.IL SEMBLE QU UNE ETINCELLE AIT AMORCE L EXPLOSION D HYDROGENE MAL EVVACUE DE LA BATTERIE EET QUI A FORME UN MELANGE DETONANNT.
S 30.DE LA BATTERIE ENDOMMAGES.
EXPLOSION/ACCUMULATEUR ELECTRIQUE/CHARIOT/VEHICULE TRANSPORT/CHARGE ELECTRIQUE/ETINCELLE ELECTRIQUE/HYDROGENE/DEGAGEMENT GAZ

** *10 77 0157 18 05 77 A H * * SIT. DANGEREUSE * AUTRES * FPC * CHARIO * DIC *
LA RESISTANCE DU CHARIOT ELECTRIQUE NO 605201 N'EST PAS PROTEGEE ET SE TROUVE PLACEE A 10 CMS DU SOL.LE CHARIOT DE MANUTENTION CONCERNE EST UTILISE POUR LA MANUTENTION ET LE STOCKAGE DE BLOCS PROPERGOLS COMPOSITES NUS OU INHIBES
RISQUE D'INCENDIE AU COURS D'UNE MANUTENTION MECANIQUE DANS UN STOCKAGE.
MANUTENTION/BLOC PROPERGOL/PROPERGOL COMPOSITE/CHARIOT/ACCUMULATEUR ELECTRIQUE/RESISTANCE ELECTRIQUE/EQUIPEMENT ELECTRIQUE/RISQUE/CONTACT ELEMENT DANGEREUX

** *12 77 0063 * 03 05 77 A H * * SIT. DANGEREUSE * PYROTECHNIQUE * FP * DEPOTS * DIC *
RISQUE DE NON FONCTIONNEMENT DES NOYAGES DES DEPOTS DE L'HEXOGENE LORS DE COUPURES DE COURANT-L'ECLAIRAGE DE SECOURS ETAIT BRANCHE SUR LES MEMES BATTERIES QUE LE DISPOSITIF ELECTRIQUE DE DECLENCHEMENT DES NOYAGES.
REVOIR LE SYSTEME D'ALIMENTATION ELECTRIQUE DE SECOURS DES NOYAGES:RESERVER UNE BATTERIE POUR LES NOYAGES.
SECURITE INCENDIE/HEXOGENE/ACCUMULATEUR ELECTRIQUE/GENERATEUR ELECTRICITE/ENTREPOT/STOCKAGE

** *98 67 9028 * 01 01 67 A H * * ACCIDENT AA * AUTRES * X * X * *
EXPLOSION D UNE BATTERIE ELECTRIQUE D UN CHARIOT ELEVATEUR.LORS DE LA REPARATION.ON VERIFIA SI LES CONTACTS MECANIQUES DANS LA BATTERIE ETAIENT BONS.ON PLACA LA LAME D UN TOURNEVIS DANS LA FENTE DU CABLE DU POLE NEGATIF ET ON ESSAYA DE TOURNER.UNE EXPLOSION EUT ALORS LIEU A CET ENDROIT,PROJETANT L ACIDE SULFURIQUE DE LA BATTERIE.
1 BLESSE
ACCUMULATEUR ELECTRIQUE/CHARIOT ELEVATEUR/MATERIEL LEVAGE/REPARATION/EXPLOSION/PROJECTIONS/ACIDE SULFURIQUE/USA

ACETATE 02 08/06/78

** *02 76 0153 * 23 09 76 A H * * INCIDENT * PYROTECHNIQUE * FA/NC * BAT54 * DIC *
COUP DE FEU SURVENU A LA BOUILLOTTE D'ACETATE EN FIN D'ENLEVEMENT DES RESIDUS NITROCELLULOSIQUES DE DISTILLATION DE L'ACETATE DE NETTOYAGE DES MATERIELS DE L'ATELIER DE COLLODIONS.
AUCUNE CONSEQUENCE
PRISE EN FEU/ACETATE/ELIMINATION DECHETS/DISTILLATION/ENTRETIEN LIEU TRAVAIL/COLLODION

** *02 77 0268 * 28 10 77 A H * * ACCIDENT AA * AUTRES * FA/NC * BAT54 * DIC *
APRES UNE O[illegible]RATION DE DISTILLATION D'ACETATE DONT LE CHAUFFAGE N'A PAS BIEN FONCTIONNE UN OUVRIER ENTREPRIT DE DEBOUCHER LES INJE[illegible]URS DE VAPEUR OBSTRUES PAR DES CONDENSATS CROYANT L'INTERVENTION TERMINEE SON AIDE OUVRIT LA VANNE DU BYPASS MAIS LA V[illegible]NE MAITRESSE ETANT RESTEE OUVERTE A TORT L'OPERATEUR RECUT UN JET D'EAU BOUILLANTE MELEE DE VAPEUR SUR LE CORPS
BRULURES 1ER ET 2EME DEGRE HANCHES CUISSE ET GENOUX DROIT ET GENOUX GAUCHE
ACETATE/DISTILLATION/VAPEUR/ELIMINATION DECHETS/INJECTEUR/FAUSSE MANOEUVRE/BRULURE/MANIPULATEUR

ACETATE CELLULOSE 02 08/06/78

** *02 74 0140 * 05 11 74 A H * * INCIDENT * PYROTECHNIQUE * FA/NC * BAT66 * DIC *
4250KG DU MELANGE D OPERATIONS DE CA 4MS5 AVAIENT ETE DESHYDRATES LORSQU UNE DEFLAGRATION S EST PRODUITE DANS L ESSOREUSE DE DESHYDRATATION A L ETHANOL PUIS AUX PRESSES A EMBALLER PAR L INTERMEDIAIRE DU TAPIS TRANSPORTEUR ET DES GOULOTTES DE LIAISON.LE SURPRESSEUR D EAU DU SYSTEME D ARROSAGE N A PAS FONCTIONNE MAIS LES POMPIERS DE L USINE ONT PU ETEINDRE L I

VOLTAGE CHECKS ON FIRING LINES USING A SPECIALLY DESIGNED NO-VOLTAGE METER

GLENN C. PRITCHARD*
BUREAU OF MINES
WASHINGTON, D.C.

ABSTRACT

Inadvertent power on the firing line, spurious electrical shorts on the ordnance item, and unwanted ground loops have all been responsible for ordnance-related accidents during test-site operations.

As a result, an ad hoc committee was organized at the Naval Weapons Center, China Lake, California to design and develop a meter with no power source that could be used to make voltage checks on firing lines before connecting electro-explosive devices (EED's).

This paper concerns itself with the ad hoc committee's design and intended use of a "No-Voltage Meter," which will clearly detect 50 millivots, AC and DC, will not result in voltage transfer to the firing line, and can eliminate the use of battery-operated meters, such as a volt-ohm meter (VOM), that could present a hazard in test-site operations.

*Mr. Pritchard was previously affiliated with the Naval Weapons Center, China Lake, California before assuming a position with the Bureau of Mines.

INTRODUCTION

On a number of occasions, both at NWC and elsewhere, personnel involved in test-site operations have triggered premature detonations, explosions, and deflagrations by hooking up firing lines that contained AC or DC voltage still within them. Accidents and incidents of this nature prompted mandatory NWC safety regulations, such as: (1) the firing line, test assembly, initiator, and personnel must be maintained at the same electrical potential at all times prior to and during hookup, (2) all power to devices on or in the immediate vicinity of the firing pad that may have a path to or an influence on either the electro-explosive device or test device shall be turned off prior to hookup, (3) a positive method of firing line control shall be provided which will insure the isolation of the firing line from all sources of power, and (4) whenever an electro-explosive device is connected to a firing line, a no-voltage check shall be made just prior to hookup, line to line and line to ground, AC and DC voltages. This last regulation was supplemented by the requirement that only meters approved by the cognizant technical department involved in the test-site operation and the Safety Department shall be used for the no-voltage check. This requirement was incorporated into NWC safety regulations to preclude problems with battery-operated meters, such as a volt-ohm meter (VOM), that have the potential for creating a hazardous situation in a test-site operation.

AD HOC COMMITTEE

An ad hoc committee was formed to determine what meters would be approved. The committee consisted of:

Robert Blackman	- Range Department
James DeSanto	- Range Department
Paul Donaldson	- Safety Department
Gordon Greene	- Propulsion Development Department
Roy Johanboeke	- Propulsion Development Department
Robert Meade	- Propulsion Development Department
Michael Osburn	- Propulsion Development Department
Glenn Pritchard	- Safety Department
Roy Pullen	- Range Department
Kit Skaar	- Safety Department

NO-VOLTAGE METER DESIGN, DEVELOPMENT AND USE

The ad hoc committee was not able to find or purchase a commerically available meter that would meet the following requirements:

1. Shall be portable and rugged.

2. Shall measure AC and DC voltages

3. Shall detect 100 millivolts with an internal impedance of 1000 ohms per volt.

4. Shall have a sufficient voltage range to prevent meter destruction if 120 volts AC are received.

5. Shall have no power source which, because of mechanical failure or fault, could result in a voltage being present on the test leads.

6. Shall have an internal-check capability to ensure proper functioning. Voltage source must be current limited.

The ad hoc committee decided to design and develop a meter which met the above list of required characteristics. The external and internal features of the meter can be seen in Figures 1 and 2, respectively. (Mr. Robert Meade, Propulsion Development Department, deserves special recognition for his actual design work and Mr. Don Johnson, Engineering Department, deserves recognition for building the prototype). A detail discussion of the meter's design and physical arrangements can be found in NWC TP 5822.[1] The electrical schematic can be seen in Figure 3 and some of the more important design parameters are mentioned below:

1. Low internal impedance so that voltages coupled with high impedances, which present no hazard, are not detected.

2. No range selections.

3. No polarity.

4. No need to interpret readings.

5. No contact capability between check voltage source and the meter circuit.

6. No heat accumulation capability because the high wattage resistor is mounted on a heat sink and is held away from the circuit board by standoffs.

[1] Naval Weapons Center. No-Voltage Meter, by Michael R. Osburn, China Lake, California, NWC, February, 1976. (Technical Publication TP 5822, publication UNCLASSIFIED).

The proper use of the meter ensures the user there is no continuous voltage on the firing line or between the firing line and the ordnance item. A voltage check is made between the two conductors of a firing line and from each conductor to the ordnance ground. The meter will clearly indicate the presence of 0.05 volts AC or DC and 120 volts AC or DC, as can be seen in Figure 4. Since the normal meter reading is zero, the internal voltage check is conducted immediately prior to and after a firing line check to ensure the meter is working properly.

CONCLUSION

A firing line check using the No-Voltage Meter will only show the presence or absence of a continuous voltage source. It will not show positively the presence or absence of static electricity. To insure maximum safety, the No-Voltage Meter must be used in conjunction with firing circuits that have been designed to prevent hazardous electrostatic accumulation.

FIGURE 1. NO-VOLTAGE METER (PANEL VIEW)

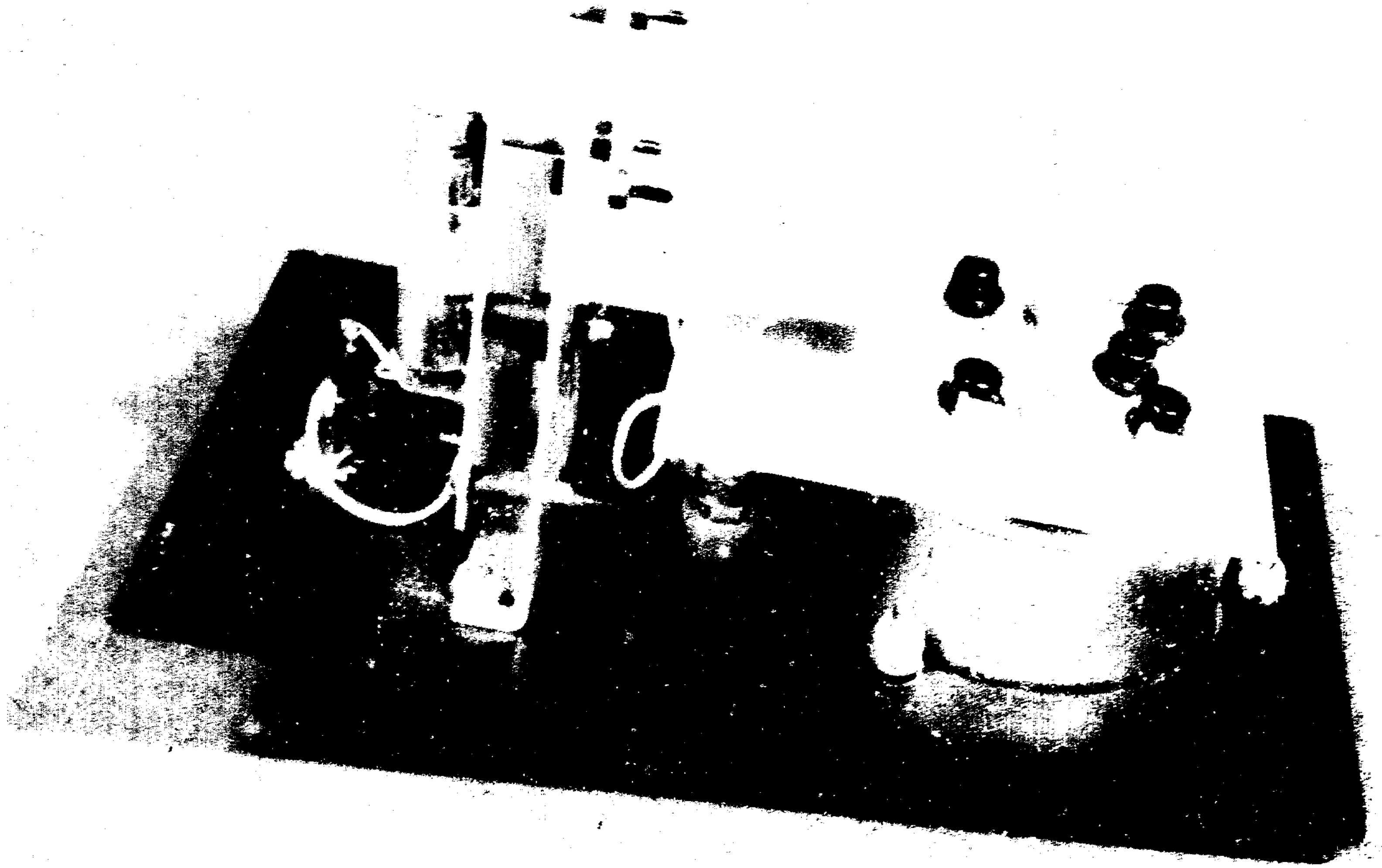


FIGURE 2. NO-VOLTAGE METER (COMPONENT VIEW)

FIGURE 3. NO-VOLTAGE METER (SCHEMATIC)

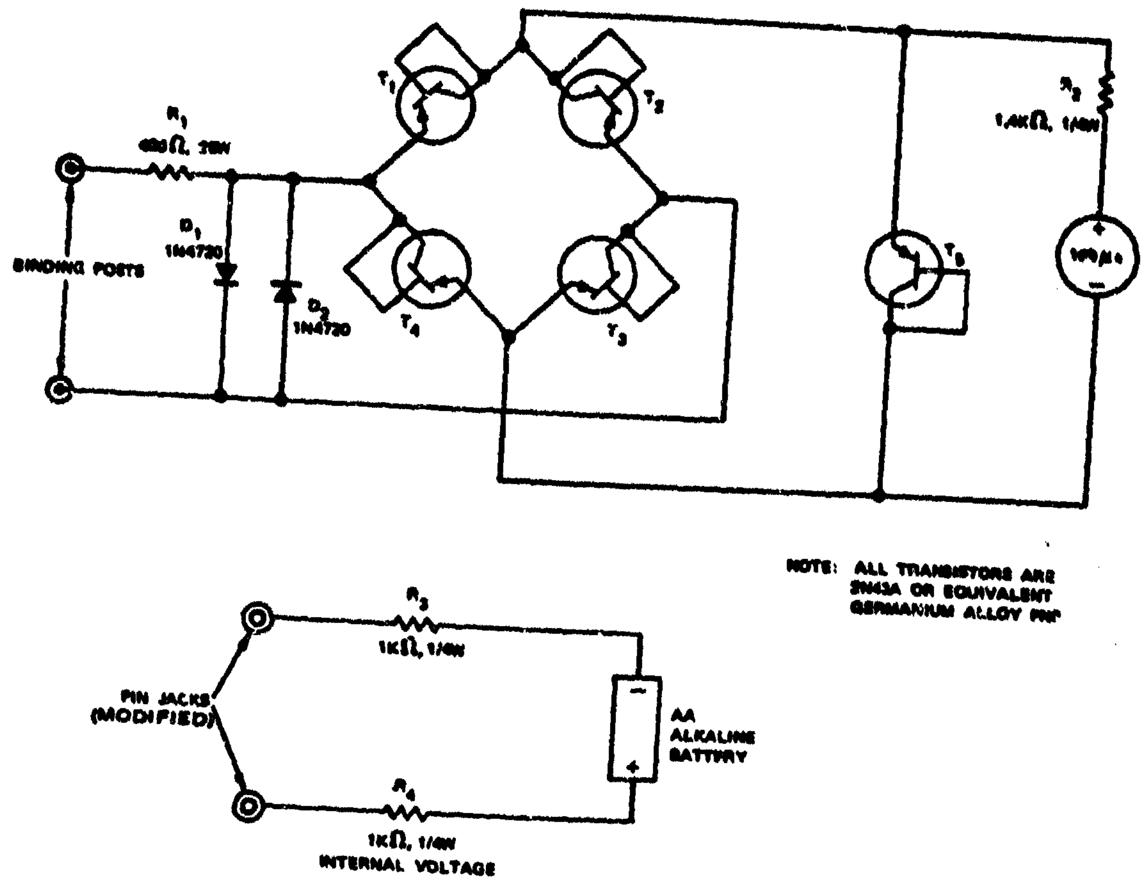
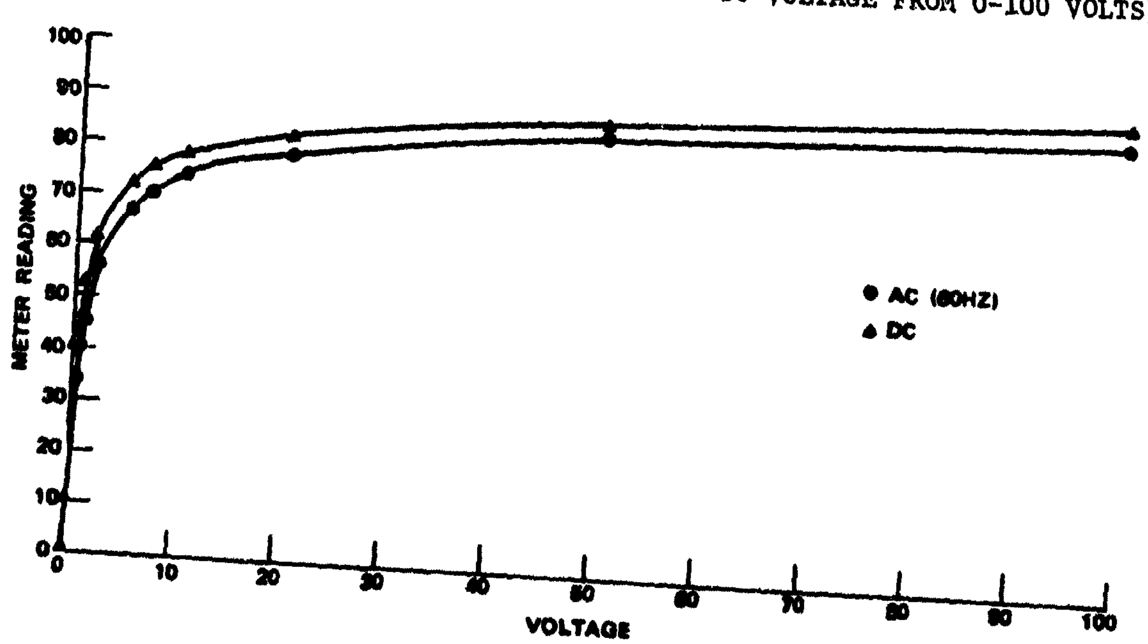


FIGURE 4. NO-VOLTAGE METER (RESPONSE TO VOLTAGE FROM 0-100 VOLTS)



ELECTRO EXPLOSIVE DEVICES (EEDs)

By
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Naval Explosive Ordnance Disposal Facility,
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Background. The safety hazards associated with inadvertent firing of EEDs such as electric blasting caps, squibs, and detonators by stray electromagnetic or electrostatic energy have been well defined. The uncertainties associated with the levels of these stray energies in field situations have led to administrative procedures to protect individuals in the operating environments. These procedures have limited the capabilities of EOD technicians in certain areas. Propcsed changes such as issuing uniforms containing polyester to EOD technicians because of the cost savings associated with standardization is compounding the problem. All of these factors makes finding a solution to both problems of immediate interest.

The Naval Explosive Ordnance Disposal Facility (NAVEODFAC) has been tasked to make all of the EOD tools safe to use in electromagnetic and electrostatic hazard areas. Since most of the tools are single-shot, explosive devices, cost becomes the prime requirement when additional capability is added. The new design also has constraints imposed by the requirement to maintain compatibility with existing blasting machines, firing leads, and established procedures.

Scope of the Task. Because of limited funding available and the requirement to address all of the EOD tools, a priority ranking was established. The blasting cap was the first priority. The M-6 blasting cap was chosen since it is widely used and EOD tools such as the X-rods are not compatible with commercial size caps. The second priority was the .50 caliber blank cartridge that is used to power the JROD, dearmer and rocket wrench. The third priority was a squib that could be used for initiating burning operations or used in such tools as the ITROD or jet perforator. The fourth priority was a filter for the firing line. Subsequent tasks would be done on a letter requirement basis.

Part I. Blasting Caps Problem:

Approach to solving the blasting cap problem: Most of the EEDs that have been approved for use in Radiation Hazards (RadHaz) environments have used a filter and heat sink combination. The filter attenuates the radiation and the heat sink transfers the heat generated away from the

bridgewire and explosive components. This was not practical with the blasting cap because:

1. It was too expensive. To be effective the filter must be coupled closely to the bridgewire leads and shielded from electromagnetic radiation leakage paths. The close coupling would destroy the filter when the blasting cap detonated. The cost goal of an additional ten cents per EED for both electromagnetic and electrostatic protection could not be met. The conventional solution would cost over ten dollars per unit.

2. It was too big. Available filters are too large to be compatible with the standard M-6 military cap (.22 caliber) or commercial caps (.25 caliber).

3. External heat sinks are impractical. Again size is the limiting factor. Also, there is no available area for the heat sink since the explosive output of the cap is usually buried in a booster or explosive.

Previously an alternate method had been investigated using ferrite beads to attenuate radio frequency energy. The approach had looked promising but had problems. These were:

1. Capacitors were required to obtain the broadband attenuation required. The combination would be too bulky to fit into the blasting cap's external dimensions.

2. The low frequency attenuation properties were not acceptable. Radar frequencies were attenuated satisfactorily but broadcast bands were not.

3. The ferrite had low Curie temperatures. If the ferrite bead was heated above its Curie temperature, it lost its attenuation. The Curie temperatures were easily exceeded when even moderate radiation was attenuated.

Recently, new ferrites have become available with high (350°F) Curie temperatures that have reasonable attenuation at broadcast frequencies. New shapes have also become commercially available. Chokes are available where only beads were previously. Chokes have a capacitive factor previously obtained by adding discrete capacitors.

Selecting the blasting cap design:

1. Ferrite formulation. After a series of laboratory tests, it was determined that the standard ferrite formulation MN-67 had the best trade-off of low frequency attentuation, broadband attenuation without detected resonant frequencies, and high Curie temperature.

2. Ferrite configuration. Laboratory testing showed that one choke configuration was superior to three beads strung in sequence. It was also determined that having each lead wind through the choke three times (1½ turns) produced the highest attenuation. The outside diameter

of ferrite chokes was selected so that when it is pushed into the blasting cap's metallic case during manufacture, a snug fit results providing good heat transfer to the entire metal case. This provides the most practical method for heat dissipation. The ferrite also has two flats molded into the cylindrical shape so that the design is compatible with automated machinery for producing blasting caps.

3. The cap design is shown in Figure 1. It consists of:

a. The standard M-6 dimensions (on the output end), explosive charge, resistance, firing current were all maintained.

b. A two diameter cap. This design was selected to prevent mistaken identity with a nonHERO approved cap.

c. The length of the cap was lengthened to 3.15 inches from 2.35 inches to allow incorporating the ferrite filter and standoff. The ferrite is separated from the phenolic plug by a standoff ferule. The standoff separates the ferrite from the explosive components to protect against cookoff.

d. The phenolic plug holds the leads to the bridgewire in place. Iron leads and nichrome bridgewire are used to prevent metallic azide formation problems. During the manufacturing process the phenolic plug is pushed in place to deform the case to obtain a reasonably tight seal. The seal minimizes water intrusion into the explosive and hydrazoic acid vapor migration from the explosive output.

e. A printed circuit consisting of a metal network deposited on a mylar substrate tape is used to dissipate both pin-to-pin and pin-to-case electrostatic potential. The tape dissipates the electrostatic potential once it exceeds 800 volts. The tape is pushed over the steel leads on the top side of the phenolic plug by an automatic machine process. The tape grounds out against the metal case.

f. The outer seal is obtained by using kraton rubber to seal the wires and cap. The whole case is then roll crimped.

Part II. Blasting Cap Status:

1. A lot of 200 caps were made on a semiautomated basis by Hercules Inc., Port Ewan, NY.

2. The caps have been fired underwater at a simulated depth of 600 feet without a failure.

3. They are compatible with EOD blasting machines.

4. They have been tested at Franklin Institute with matched impedance input power as high as ten watts at radar frequencies, four

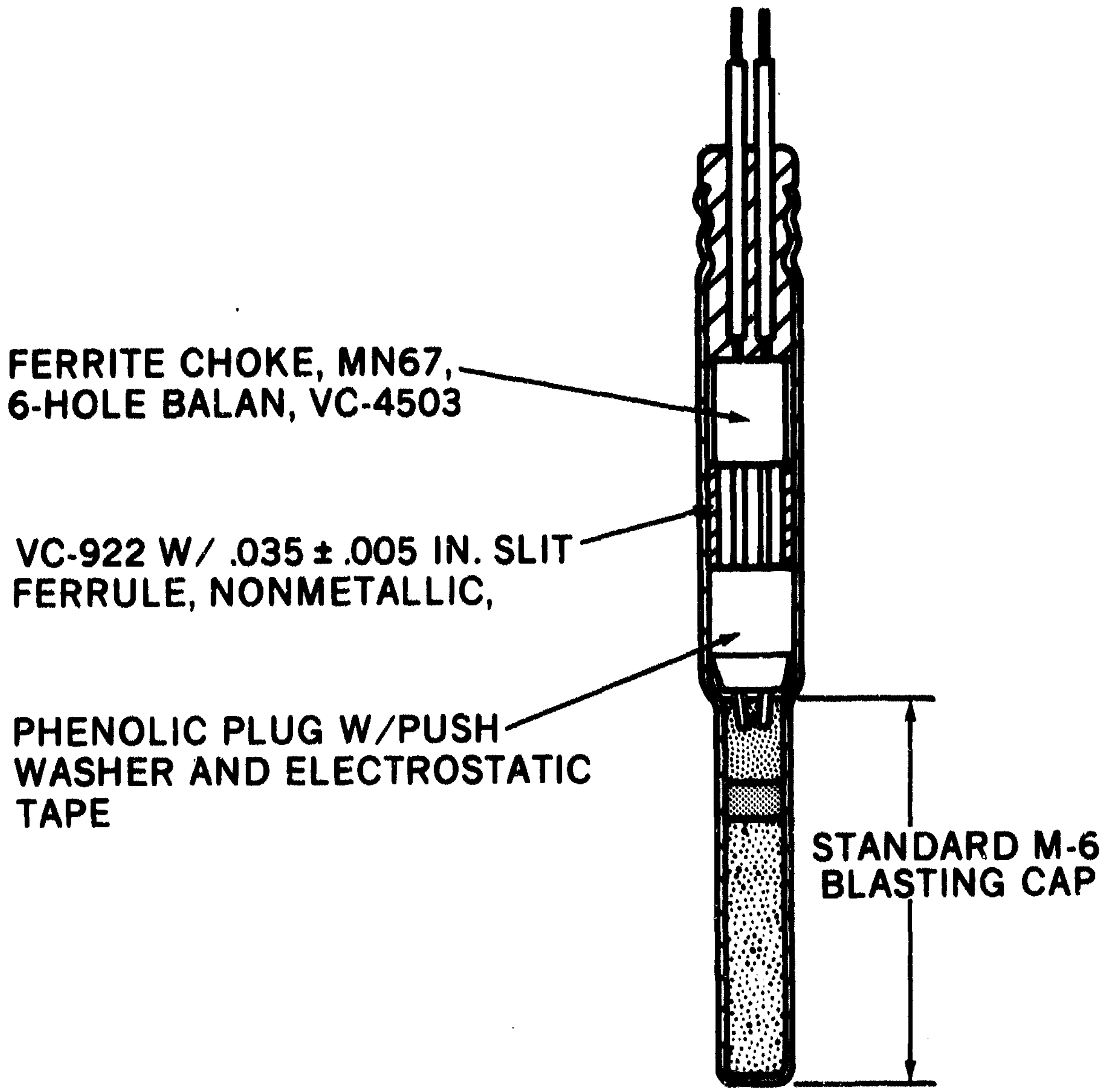

FIGURE 1 HERO & Electrostatic Resistant Blasting Cap

watts at 100 Megahertz, and two watts at broadcast frequencies for several minutes each without detecting any breakdown in the attennation. All of the testing is reported in Ref (1). Cookoff does not appear to be a problem.

5. Twenty caps (without explosive output) have been tested at NSWC, Dahlgren. The caps passed the MIL STD tests at radar and broadcast frequencies. One cap fired its bridgewire at ten feet from a 15 Kilowatt nondirectional antenna operating between 200-400 Megahertz. The cap was tested during a rain storm. The ferrite choke attennated the RF to the extent that raindrops striking the cap were turned to steam and the Kraton rubber seal extruded out the back of the cap. It is estimated that the Kraton would have to approach 400^{o}F before such extrusion would take place. The ferrite provided an unexpectedly high protection factor.

6. The caps have successfully withstood electrostatic potentials as high as 60,000 Volts without firing. That value is in excess of what a person is capable of carrying even wearing synthetic clothing.

7. The USN has purchased tooling to produce the chokes. The cost in production is estimated to be approximately 4 ½ cents per unit.

Part III. Blasting Cap Plans:

1. Once the cap has received a conditional clearance (not to be used within some specified distance of a operating antenna) the remaining caps will be field evaluated by EOD units.

2. After the design is cleared, official nomenclature will be obtained and Approval for Service Use (ASU) requested.

3. After ASU the design will be offered for standardization by DOD and NATO.

4. The design will be offered to interested commercial producers.

If all of the above steps occur, a yearly output of 10,000,000 units could be expected to be produced. Such large quantities would substantially decrease the present cost of the M-6 from $2.34 to a cost approaching $1.50/unit, including the additional protection features.

Conclusion: A low cost, blasting cap resistant to stray electromagnetic and electrostatic energy has been developed. It is the first step and goes a long way toward solving the problems of personnel operating in unknown electrostatic and electromagnetic radiation fields. For radar frequencies, generally, if it is safe for the technician to be in the radiation field, the blasting cap is safe to use. The ferrite choke that was developed for the cap has applications in other devices.

.50 CALIBER CARTRIDGE

Approach to Solving the Cartridge Problem: The current design of .50 cal cartridge uses a MK 1 Mod 2 squib to electrically initiate a mixture of propellants. The squib has leads that extend from the case making the design unacceptable by current HERO standards. A survey of alternative designs was investigated to determine which would provide the lowest cost. The design of other HERO safe cartridges were studied to define successful alternatives. The design that resulted is shown in Figure 2. The design elements are as follows:

1. Ignition elements: The MK 14 Ignition element was selected on the basis of following criteria:

a. It is a widely used, standard item that costs $.60/unit when purchased in quantities of 100,000 or more. Wide production experience and experience in manufacturing cartridges containing this element is available.

b. It is recognized as HERO safe when properly installed with a standoff distance to prevent shorting.

c. It fits into the .50 cal cartridge base.

d. Its design is electrostatic resistant since it is a single lead squib with grounded case.

2. The propellant is being changed from a mixture of three components to a single propellant to minimize cost while matching the ballistic performance. One ingredient in the three component mixture is hydroscopic, indicating a potential problem may develop. The proposed substitution is not hydroscopic.

3. The closure disk is unchanged from the present design.

4. Every effort will be made to eliminate the wadding.

5. Potential moisture leak pathes have been minimized. An epoxy sealant will be used to further minimize this potential problem.

6. A HERO safe filter is planned to attenuate electromagnetic radiation in the firing line before it can enter the ignition element.

7. The firing pin in the breech cap is the design used to fire the MK 14 ignition elements in bomb ejector cartridge in aircraft ejector racks.

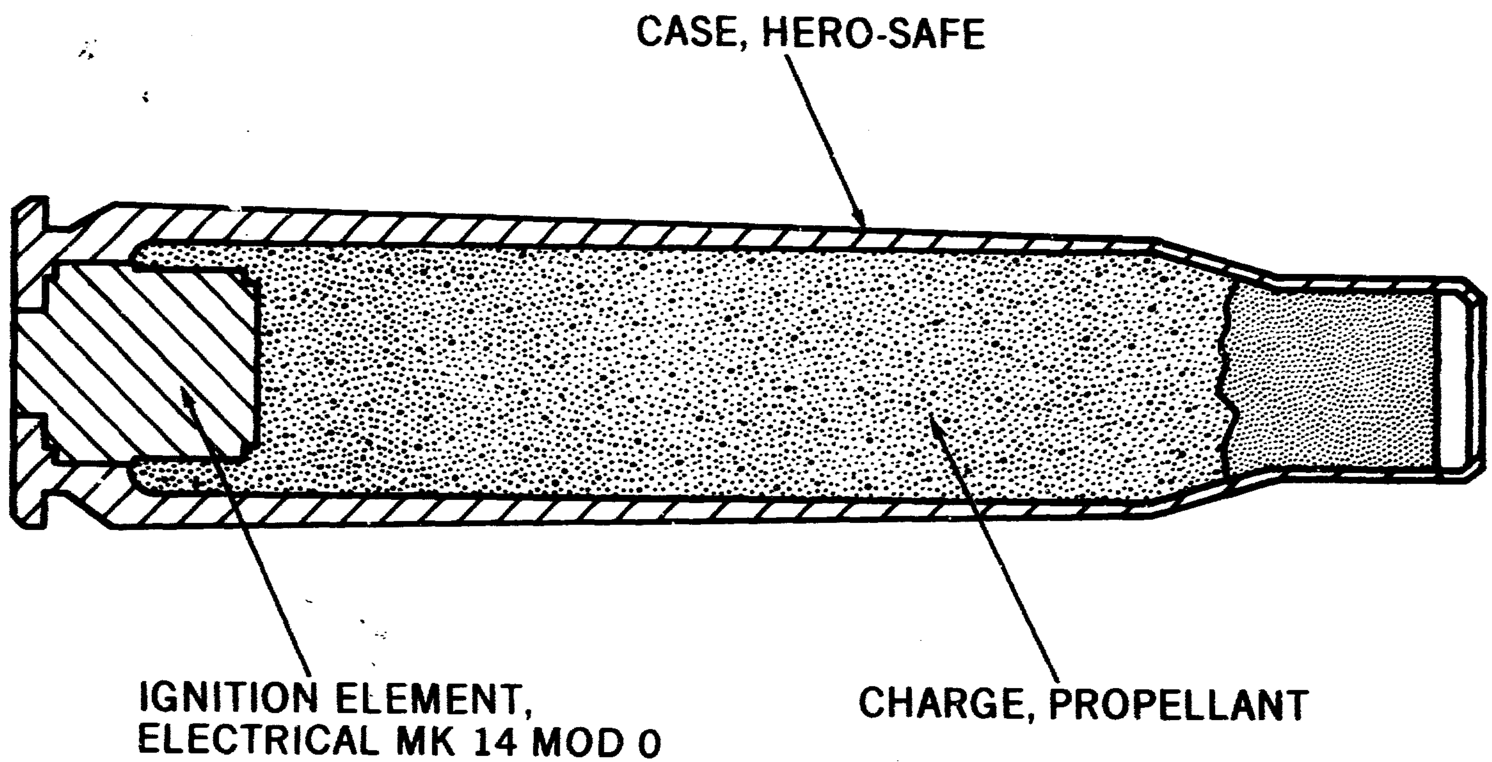

FIGURE 2

HERO & Electrostatic Resistant Cartridge

CARTRIDGE STATUS:

1. A pilot lot of 300 blank brass cases have been received and the primer pocket machined to accept the MK 14. The ignition elements have been pressed into these cases.

2. Closed bomb tests have been completed and candidate propellants selected to match the ballistic performance of the mixtures.

3. Firings were conducted over the temperature range of 0-100°F to prove the ballistics.

4. Two hundred rounds are being manufactured to a prototype documentation package.

PLANS:

1. The design will be submitted for HERO certification.

2. Additional firings will be done to prove out the cartridges ballistics.

3. The design will be submitted for ASU.

SQUIBS

Approach: The EOD technician needs two types of squibs in order to carry out his duties. The first is a squib that functions at ambient pressure and starts burning operations of combustible scrap material. The second type fits into a device and must burn at some elevated pressure while maintaining a gas tight integrety. This type is used in EOD tools that require a burning grain.

It was decided that the lowest overall cost device that would meet both of these needs would be a modular squib. The bare squib would perform the ambient temperature burn and by attaching a threaded outside receptacle, the squib could be made to perform the second function of high pressure burning. Changing the outside configuration would allow the squib to be used in any tool. It was further decided that using as many of the HERO resistant parts used in the blasing cap as possible and making the design compatible with a high speed blasting cap line would result in the lowest practical cost. Another cost saving factor was that once the basic design of the squib was declared HERO safe, only a drawing review of its use would probably be required to get new EOD tools declared HERO safe. Figure 3 shows the concept that has evolved. Further improvements may become evident as testing progresses.

Design Concepts:

The metal case, wiring (length, type, size and wrap), foil safety shunt, electrostatic shunt, kraton seal, ferrite choke, stand off ferrule, phenolic plug and bridgewire are identical to the ones used in the HERO and electrostatic resistant blasting cap. The bridgewire-ignition-mix has been changed and the explosive output has been changed to a fire producing fluorocarbon grain. The grain is extruded fluorocarbon mix PL6239 with an outside diameter of 0.25 and an inside diameter of 0.100 inches.

The squib functions in the following manner:

1. DC power ignites the bridgewire-ignition-mix.

2. The burning material starts the center perforation of the hollow fluorocarbon cylinder on fire.

3. Gas buildup and hot particles rupture the end of the metal case allowing the burning fluorocarbon residue to escape.

4. The fluorocarbon grain continues to burn from the inside out. The length of the burn being inversely proportional to the internal pressure.

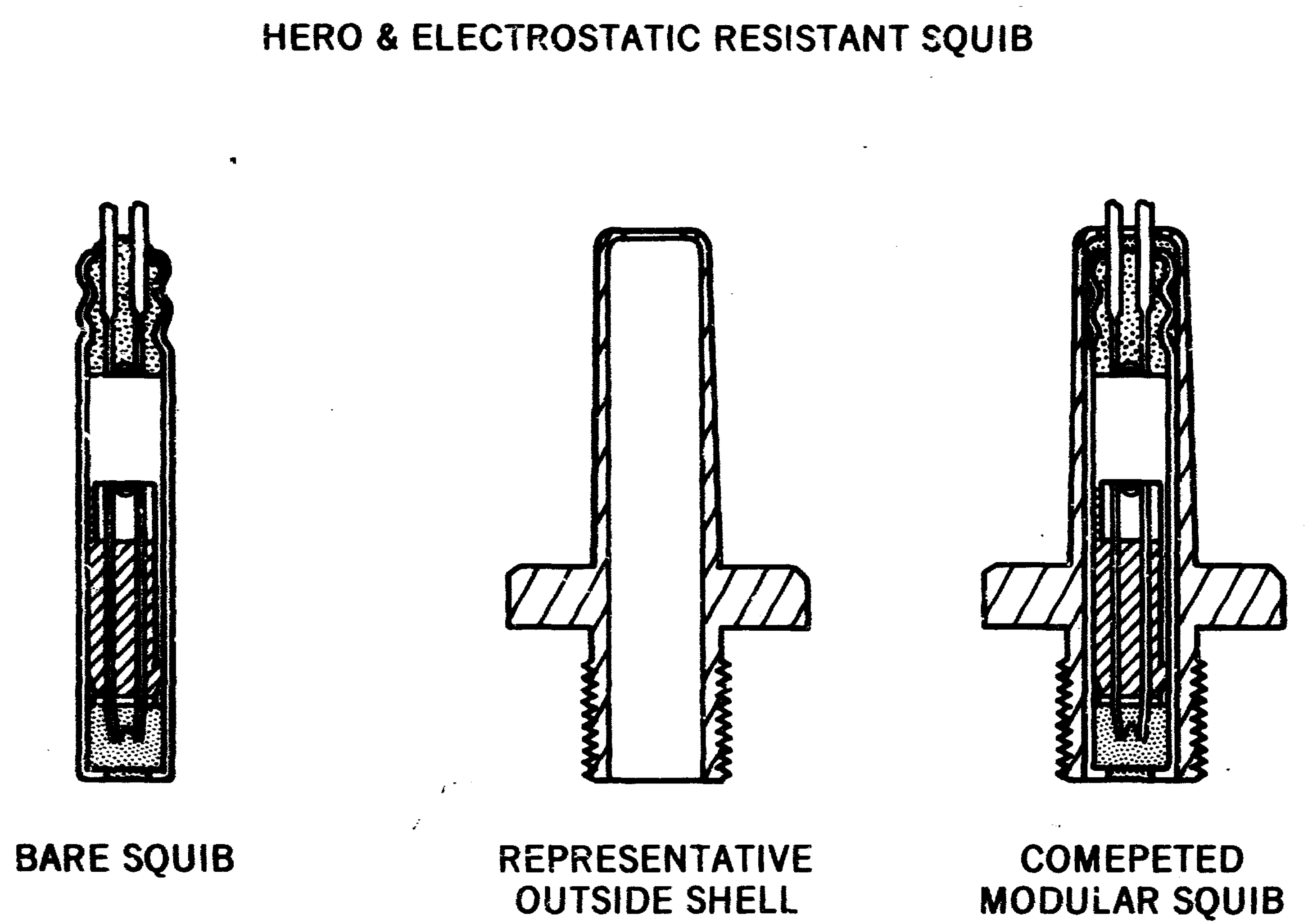

FIGURE 3

SQUIB Concept Under Development

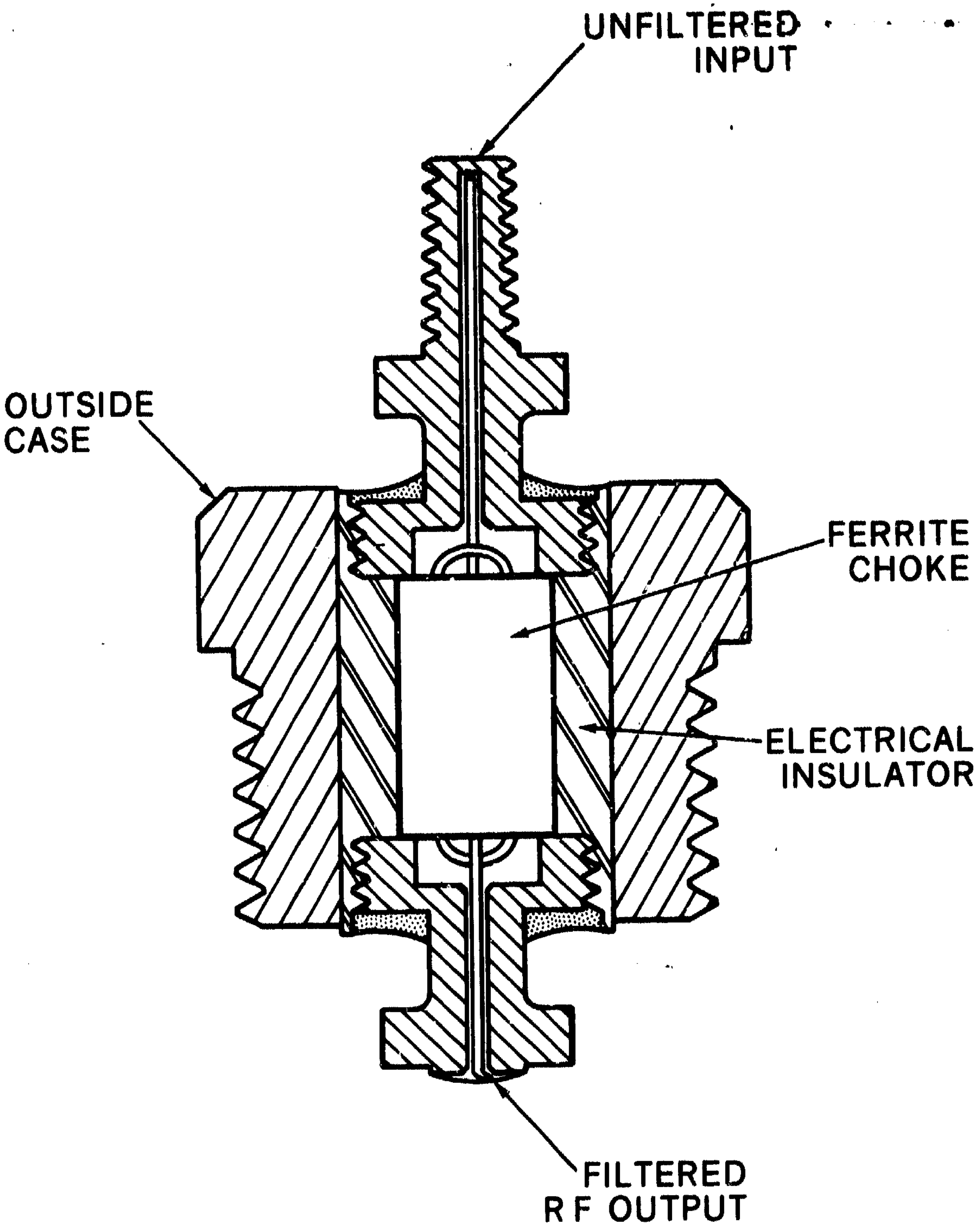

FIGURE 4

Proposed Firing Line Filter

STATUS:

A contract has let to manufacture a lot of 200 squibs incorporating all of the ideas outlined in the concept. These squibs will then be tested for functionality, performance, reliability, etc.

FIRING LINE FILTER

As part of the task for FY81 the NAVEODFAC will investigate placing one or more of the MN-67 ferrite chokes into a housing. This unit will be used to filter out stray RF on EOD Firing Lines. This approach if successful will cut the cost of an acceptable filter by at least ½. The artist's concept drawing is shown in Figure 4.

20, 25 and 30mm ELECTRICALLY FIRED PRIMERS

As the result of the work with the MN-67 choke, a new concept has been proposed. The choke will be wound so that the conductive lead is in the shape of a watchspring. A short cylinder nicknamed the "pancake filter" will be molded with the conductive lead imbedded inside. A conductive area on each end of the short cylinder will provide conductive areas similiar to the button currently used in 20, 25, 30mm primers. It is proposed to investigate this concept in a sequential manner. The project would proceed from fabrication of the pancake primers through the evaluation of fully assembled primers. Since this area is outside of the scope of the EOD effort this proposal has been submitted to the Naval Air Systems Command for evaluation.

CONCLUSION:

The task to make all EOD tools resistant to spray electromagnetic and electrostatic energy has developed a significant new low cost concept. The use of the MN-67 choke appears to have wide application for EOD and others working with sensitive EED's. From the test results it appears that serious consideration should be given to standardization of the blasting cap because of its increased safety at nominal cost. If the standardization is accomplished a cost saving will probably result. The cost savings to DOD could amount to as high as 40 percent if blasting cap is utilized for commercial blasting.

References:

1. *Franklin Research Center Final Report FC 5067 "RF & Electrostatic Testing of Detonators" Dec 1979*

THE EXPLOSIVE HAZARD PRESENTED BY THE TORPEDO MAGAZINE OF A GUIDED MISSILE FRIGATE (FFG-SERIES) DURING PIERSIDE TOPPING-OFF OPERATIONS

by

Gruver H. Martin
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ABSTRACT

As part of the Navy Explosive Safety Improvement Program (NESIP) a series of experiments was conducted to determine the nature and magnitude of the explosive hazard presented by the torpedo magazine of a new series of guided missile frigates (FFG-series), during pierside topping-off operations. Studies were made of the threat imposed by an accident in the 76mm gun magazine above the torpedo magazine; the interaction between torpedo warheads; and the contribution of Otto Fuel, in a confined environment, to the hazard potential. Results indicate that, by slightly altering the torpedo storage arrangement and using relatively simple shielding techniques, the maximum credible event (MCE) can be reduced to the donor shell or torpedo.

As a part of the Navy Explosive Safety Improvement Program (NESIP) a series of experiments was conducted to determine the nature and magnitude of the explosive hazard presented by the torpedo magazine of a new series of guided missile frigates (FFG-series), during pierside topping-off operations. Studies were made of the threat imposed by an accident in the 76mm gun magazine above the torpedo magazine; the interaction between torpedo warheads; and the contribution of Otto Fuel, in a confined environment, to the hazard potential.

BACKGROUND

To understand the threat presented to the torpedo magazine by the accidental detonation of an explosive round in the 76mm gun magazine, one needs to observe the relative positions of the two magazines on the FFG-7 as shown in Figure 1. As one can see, the torpedo magazine is on the main deck while the gun magazine is located one deck above at the 01 level. The gun magazine is centrally located on the ship centerline, while the torpedo magazine is almost completely on the port side of the ship. The shaded area shows where the overhead of the torpedo magazine and the deck of the gun magazine are contiguous. However, except when torpedoes are being moved to or from their normal storage position (as shown by torpedo on craneway), the stored units are confined to the area shown. Hence, the overlapping area is the small strip shown by the cross-hatching.

The NESIP Program had previously determined, by extensive testing and analyses (not reported in this paper) that the maximum credible event for generating fragments of sufficient energy to penetrate the magazine deck or bulkheads is one 76mm round. Hence, the tests in which the 76mm magazine threat is discussed have all been designed with the assumption that one 76mm bare round detonates in the 76mm magazine at the closest possible distance from a Mk 46 acceptor torpedo. The balance of the tests were designed to study the effect of burning or detonating MK 103 warheads in torpedo magazine storage arrangements.

This paper describes and reports only the testing conducted as a part of this program. It does not attempt to describe any of the analytical studies conducted as an integral part of the program. The analytical studies will be partially described by Porzel in another paper presented in this seminar[1].

TESTS TO DETERMINE THE EXTENT OF THE THREAT FROM THE 76mm MAGAZINE

Several tests were made to determine what effect, if any, an exploding 76mm round in the gun magazine would have on the stored MK 46 torpedoes in the torpedo magazine below. The acceptors, in each case, were either all-up MK 46 torpedoes, MK 103 warheads or simulated MK 103 warheads. All warheads were loaded with PBXN-103 explosive. The material used to represent the deck of the gun magazine in every test, except one, was 1/4" thick 5456-H321 aluminum. The distance between the donor 76mm round and the acceptor was maintained at 48". In two of the tests, the acceptors were unconfined. In each of the others, the acceptor was severely confined.

1. Porzel, F. B., "Technology Base of the Navy Explosive Safety Improvement Program", 19th DDESB Seminar, Los Angeles, CA, 12-14 Sep 1980.

TESTS WITH UNCONFINED WARHEADS

Two tests were made with unconfined warheads (see Figure 2). In the first test, the projectile of the 76mm round was placed directly over a Mk 103 warhead. Since the projectile was nose initiated, most of the resulting fragment spray missed the acceptor. There were several fragment hits, but only one penetration occurred when a fairly large fragment struck a glancing blow on the side of the warhead case. This hit resulted in a momentary flash at that point. Otherwise the warhead was undisturbed. It neither burned nor detonated.

This test result indicates that the probable hazard to the torpedo magazine is small for purely geometric reasons: The donor must explode not just directly over the torpedo, but in some specific position such that the side spray -- a relatively narrow zone -- happens to strike the acceptor torpedo broadside. For typical sidespray dimensions and donor/acceptor separations, a spread of approximately 3 feet is possible for a "dangerous location". Even then, the acceptor torpedo must be broadside to the spray; otherwise, the fragments will strike at a glancing incidence and be innocuous.

For the second test, the 76mm round was moved forward 6" to assure a maximum fragment spray on the Mk 103 warhead. This resulted in fragment penetration of the acceptor case. A small fire started on one side of the acceptor and gradually spread to the entire warhead. The warhead was consumed after about two minutes of vigorous burning. Note that the acceptor burned to completion, without deflagration or detonation (Deflagration-to-Detonation-Transition did not occur) even though the PBXN-103 was confined in its case.

TESTS WITH CONFINED ACCEPTORS

Three types of tests with confined acceptors were made. These were: (a) tests with simulated all-up torpedoes (real warheads and fuel tanks, but simulated electronics), to determine if the Otto Fuel contributes to the hazard) (b) a test with Mk 103 warheads only, (c) tests with inhibitors, to determine the nature and arrangement of inhibitor material required to prevent initiation of the warheads in the torpedo magazine.

TESTS WITH ALL-UP TORPEDOES

Two tests were made with simulated all-up torpedoes (see Figure 3). For each test the all-up Mk 46 torpedo (consisting of a 13-3/4" (length) simulated electroncs section, a 13 1/2" (length) warhead section and a 40" (length) Otto Fuel filled fuel tank) was centrally placed on the bottom of a buried 4' x 4' x 12' steel tank. The top of the tank was covered with 1/4" thick steel plate except for a 4' x 4' section over the acceptor target area. This area was covered with 1/4" thick 5456-H321 aluminum. The donor was a bare 76 mm projectile. In the first test, the fragment spray from the projectile was directed at the Mk 103 warhead, and in the second test, the projectile spray was directed at the fuel tank. Thermocouples were used to monitor the air temperature in the tank, and the temperature of the fuel tank. A pressure gage was mounted in the side of the tank to monitor the quasi-static tank pressure; two surface mounted pressure gages (one 10' and one 20' from the center of the tank) were provided to measure air blast should detonation occur,

In the first test, the fragment spray from the donor projectile was directed at the warhead. Two and one-half seconds after the initiation of the donor projectile, the torpedo warhead ignited. It burned (no deflagration) vigorously for about two minutes, and then subsided. About 2 1/4 minutes after donor initiation, the Otto Fuel ignited and burned for another 3 3/4 minutes. A subsequent view of the test box revealed that the warhead section was completely melted down, while the electronics section and fuel tank section were essentially intact. However, the aft bulkhead of the fuel tank had been pushed out (probably by the heated, expanding Otto Fuel) allowing the fuel to escape and cover the bottom of the test box, where it was eventually ignited by the burning warhead. The temperature of burning Otto Fuel exceeded 500° F, but was certainly less than 1200° F., since the aluminum case melted only in the region of the warhead itself. The recorded airblast supports the visual observation that neither the explosive in the warhead nor the Otto Fuel detonated, nor violently deflagrated.

In the second test, the fragment spray from the donor projectile was directed at the Otto Fuel tank. About two seconds after the initiation of the donor, there was a burst of flame from the test box. The flame disappeared, then reappeared one second later. The Otto Fuel burned vigorously for 4 3/4 minutes. At this time, the warhead deflagrated and several pieces of burning warhead and debris blew out of the hole. The total burning time was about 9 minutes. In spite of the deflagration of the warhead, there was no measureable airblast - indication that the deflagration was quite mild. Unlike the first test, nearly all of the aluminum parts (electronics section, warhear and fuel tank) were melted down or consumed in the fire, indicating that the temperature environment was severe over a much larger region.

TEST WITH TWO CONFINED MK103 WARHEADS

The purpose of this test was to determine the effect of confinement on the rows of torpedoes in the torpedo magazine from activation by fragments from the 76 mm magazine above. The degree of confinement was deliberately severe to exagerate the effect of confinement. Actually, because of the large volume of the magazine, the stored torpedoes are essentially unconfined. The test setup is shown in Figure 4. The two MK 103 acceptors were placed 12" apart (the distance between rows of torpedoes in the magazine) on the bottom of a 4' by 4' x 5' steel box. The donor 76 mm round was aligned to assure a maximum fragment spray on one of the acceptors. The intent was to ignite one warhead with the fragment spray and observe how the other warhead was affected by its burning neighbor. However, it appeared that both acceptor warheads were ignited by donor fragments. Acceptor ignition occurred seven milliseconds after donor initiation, and the total burning time was less then half a second, which was quite different from the relatively slow burn (approximately two minutes) of the unconfined warhead. There was no detonation - rather a "soft" deflagration, as indicated by the half second burning time and the almost complete lack of debris ejected from the hole (five small pieces were recovered - all within 70' of GZ). A range of seventy feet corresponds to an ejection velocity like forty-five feet per second at a 45° loft angle; this is a hundred times too small to represent a detonation. A fragment at seventy feet could result from a higher initial velocity, if it were ejected nearly vertically, but this is still far short of detonation.

TESTS WITH INHIBITORS

An inhibitor is a device which either prevents the donor munition from causing a reaction in the acceptor munition, or reduces the magnitude of the reaction to the point that it is an acceptable hazard. Two areas, in which inhibitors might prove beneficial in eliminating or reducing the potential threat, were investigated. These were: (a) the threat imposed on the torpedo magazine by the 76 mm magazine and, (b) the threat between torpedoes in the torpedo magazine as the result of an accident in that magazine.

TESTS OF INHIBITOR DESIGNS TO REDUCE 76 mm MAGAZINE THREAT

Three different designs were tested. The arrangement for the first two tests is shown in Figures 5 and 6. In these tests, steel inhibitor plates 1/2" and 1/4" thick were placed 6" below the simulated gun magazine deck. The donor was a cased 76 mm round 4" above the deck and the acceptor was a confined MK 103 warhead 48" below the deck plate. In the first test, the 1/2" steel inhibitor plate was deformed downward about 6" in the area under the 76 mm donor. There were approximately 20 fragment strikes, yielding indentations ranging from 1/8" to 1/4". There were no penetrations - hence no fragment marks on the warhead. In the second test, the 1/4" steel inhibitor plate was deformed about 10" downward. There were approximately 15 near penetrations and two penetrations (one 1 1/2" x 2" - 11" off center and one 1/2" x 1/2" - 2" off center). There were no visible marks on the acceptor warhead.

The setup for the third test is shown in Figure 7. In this test, a 1/4" thick steel inhibitor plate was placed 6" above the simulated gun magazine deck. The acceptor warhead was simulated by a 1/4" thick aluminum plate placed 42" below the deck plate. In this test, both the inhibitor plate and the deck plate were holed. While there were no penetrations of the 1/4" aluminum plate simulating the torpedo warhead, there were many near penetrations and over 60 fragments were found on this plate after the shot. It would appear that, by placing the inhibitor in this location, the number of fragments entering the torpedo magazine space were greatly increased, presumably, by contribution from the steel inhibitor plate[2].

TESTS OF INHIBITOR DESIGNS TO MINIMIZE THE INTERACTION BETWEEN TORPEDOES IN THE TORPEDO MAGAZINE

Some typical distances between warheads of stored torpedoes in the magazine are shown in Figure 8: 3.25", 9.25", and 14.25" We know from early acceptance tests conducted by the Naval Weapons Center, China Lake[3], that uninhibited MK 103 Warheads will sympathetically detonate at separations as great as 24". So, it would appear that, without successful inhibition, the maximum credible event would be the entire magazine load.

The first three tests were designed to determine the effectiveness of such a 1/4" steel inhibitor plate midway between warheads at each of the separations shown in Figure 8. The overall test setup for these three tests

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2. Porzel, F. B., "Design of Lightweight Shields Against Blast and Fragments", Minutes of 17th DDESB Seminar, Denver, CO., 14-16 Sept 1976.

3. Unclassified Data from a Classified Source

is shown in Figure 9 and the close-up of a typical warhead and inhibitor arrangement in Figure 10. The donor and acceptor warheads were placed on a 2" thick steel witness plate at the required separation with the inhibitor plate midway between; a replicate inhibitor plate was placed 90° around the donor and a Celotex pack positioned 25' away to sample fragments from this plate, so that plate break-up could be studied.

Two flash panels were placed on the donor acceptor centerline 40 feet from the inhibitor plate. These flash panels served two functions - (a) to measure typical fragment velocities on both the donor and acceptor sides, and (b) as an additional indicator of whether the acceptor detonated. If the acceptor did not detonate, it would serve as a shield for fragments from the donor - thus, a comparison of the donor and acceptor flash panels would provide additional evidence of acceptor reaction. Airblast gages were also provided in an attempt to provide back-up information as to whether one or two warheads detonated.

The results of the three tests are shown in Table I. These results show that an inhibitor of this type could prevent sympathetic detonation between adjacent warheads in the horizontal and diagonal directions, but not in the vertical stacking mode (3.25" separation).

TESTS WITH ALUMINUM INHIBITORS

On a visit to an FFG-7, it was noticed that the chocks used to hold and restrain the torpedoes in storage, while made of aluminum, were fairly heavy. They did not cover the entire warhead, but if they could be redesigned to completely cover the warhead, and the torpedoes were stored nose to tail (as suggested two years ago) - See Figure 11 - we would have a stowage arrangement very much like the set-up for the next test. (See Figure 12). The overall test arrangement was the same as used for the steel plate inhibitors.

The test results were essentially the same as tests 1 and 3 with the steel inhibitors. The acceptor warhead did not detonate; (a) There was only one hole in the witness plate, (b) there were many fragment holes in the donor flash panel - none in the acceptor flash panel, (c) several large fragments from acceptor found, (d) burning explosive thrown as far as 800 feet.

Having determined the effectiveness of the chocks in preventing sympathetic detonation, we wanted to see how effective they would be in containing a burning warhead. Two tests were made: (a) one with the warheads under conditions of extreme confinement, (See Fig. 13), and (b) the warheads in the open (See Fig. 14). In both tests, the donor warhead was ignited rather than detonated.

In the test using the confined configuration, both donor and acceptor were consumed. The acceptor deflagrated (three distinct reactions occurred) approximately 50 seconds after donor initiation.

In the test conducted in the open, the donor burned completely and melted a portion of its own simulated chock material, but did not affect the simulated chock material of the acceptor nor the acceptor itself in anyway. A thermocouple on the backside of the chock plate showed only a 50° temperature rise. A thermocouple inside the acceptor well showed no temperature rise whatever.

CONCLUSIONS

On the basis of these tests, it is our conclusion that the Maximum Credible Event (MCE) produced by an accident in the gun or torpedo magazine can be reduced to one donor shell or torpedo (NOTE: By MCE, we do not mean no reaction in the acceptor--simply no high order reaction. Fire or deflagration is acceptable). This can be accomplished by the following means:

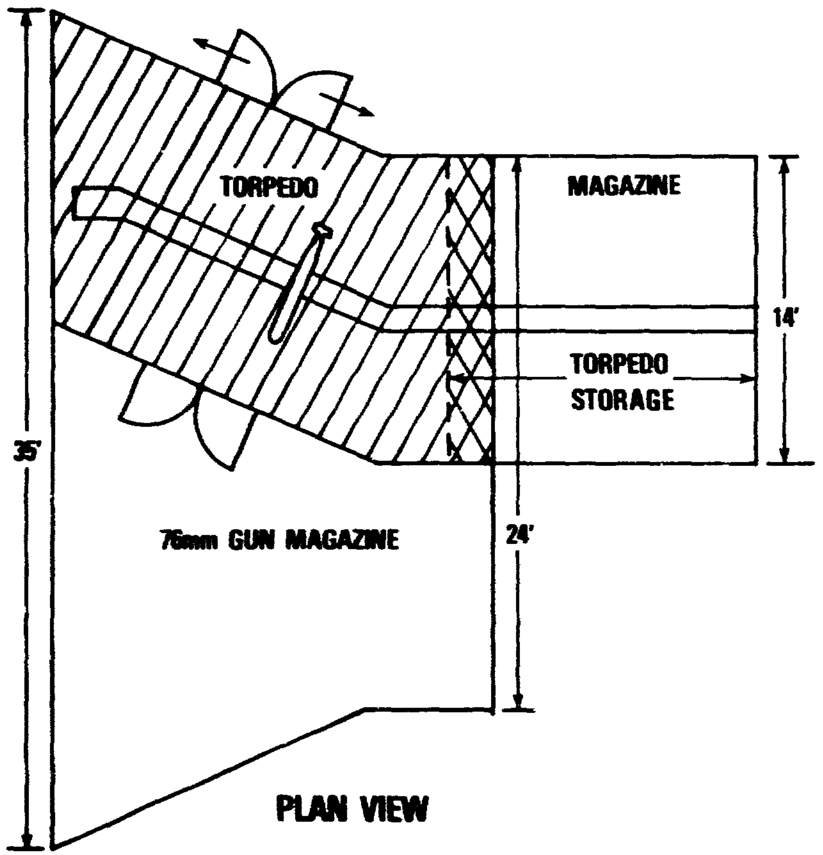
(a) Altering the stowage arrangement in the magazine, such that the torpedoes are stowed alternately nose to tail,

(b) Extending the existing chock design to cover the entire warhead, and

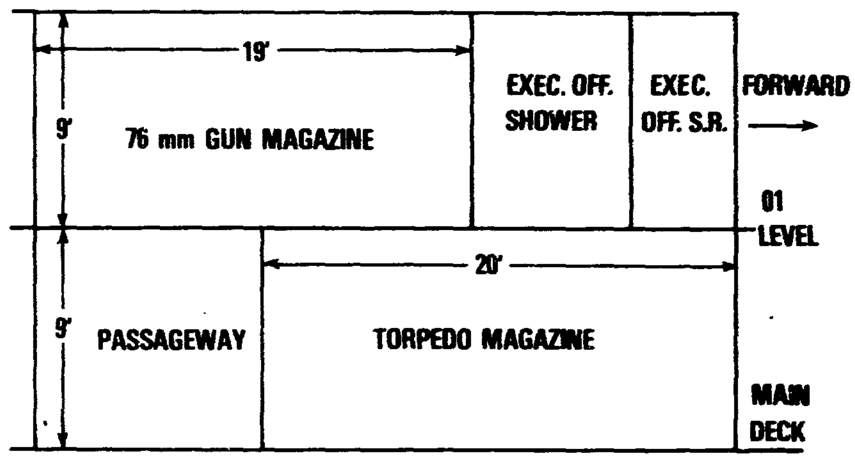
(c) Providing proper protection in the critical areas of the torpedo magazine (e.g., 1/2-inch of steel suspended 6-inches below the overhead.

In addition, the tests indicate that the probable hazard to the torpedo magazine from an accident in the 76 mm magazine is small for purely geometric reasons.

FIGURE 1
SHIP LAYOUT



PLAN VIEW



ELEVATION VIEW

FIGURE 2
TEST SET-UP

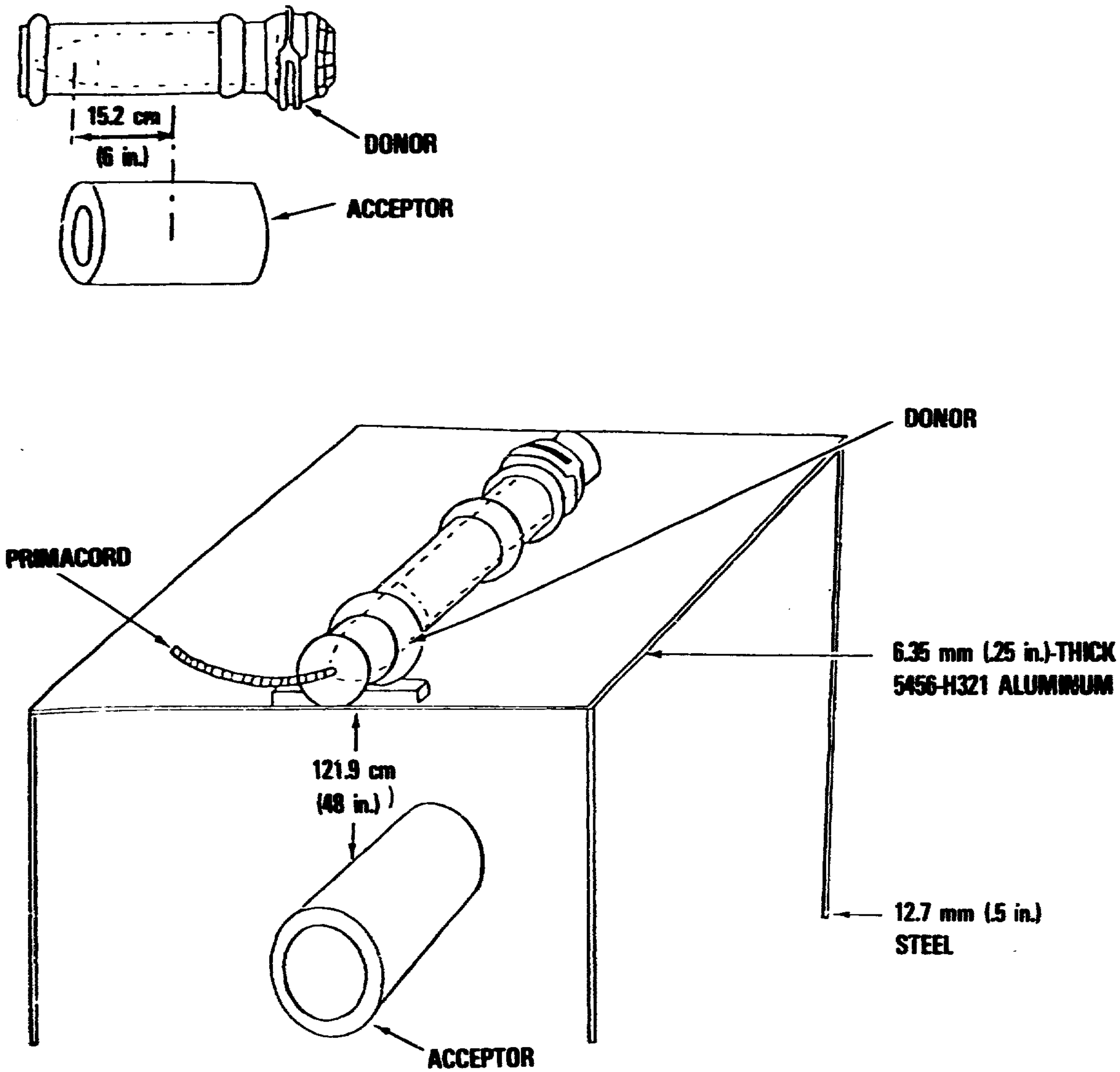


FIGURE 3

PLAN AND SIDE VIEW OF SIMULATED ALL-UP MK 46 TORPEDO TEST. (4' x 4' x 12' BOX)

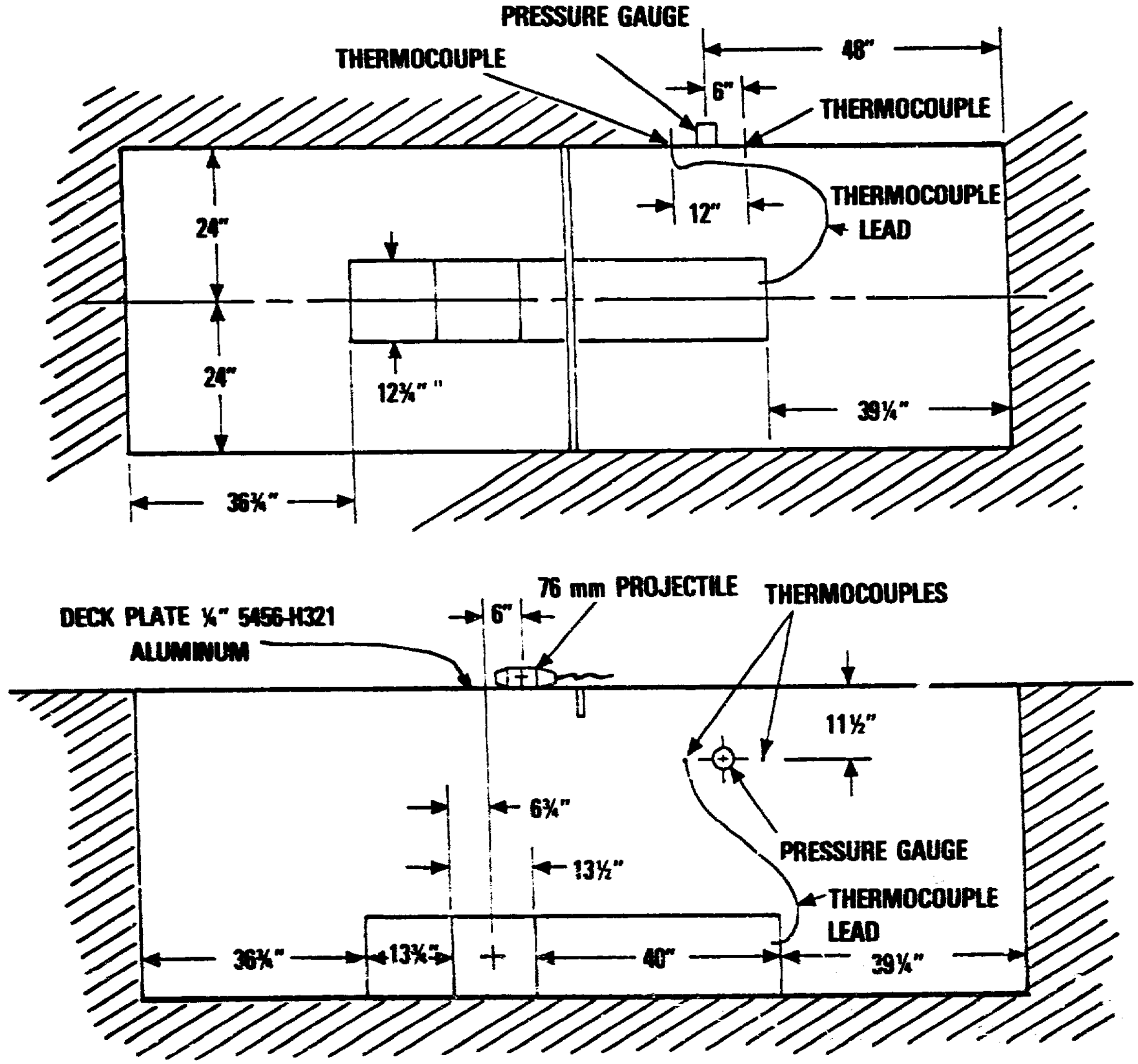
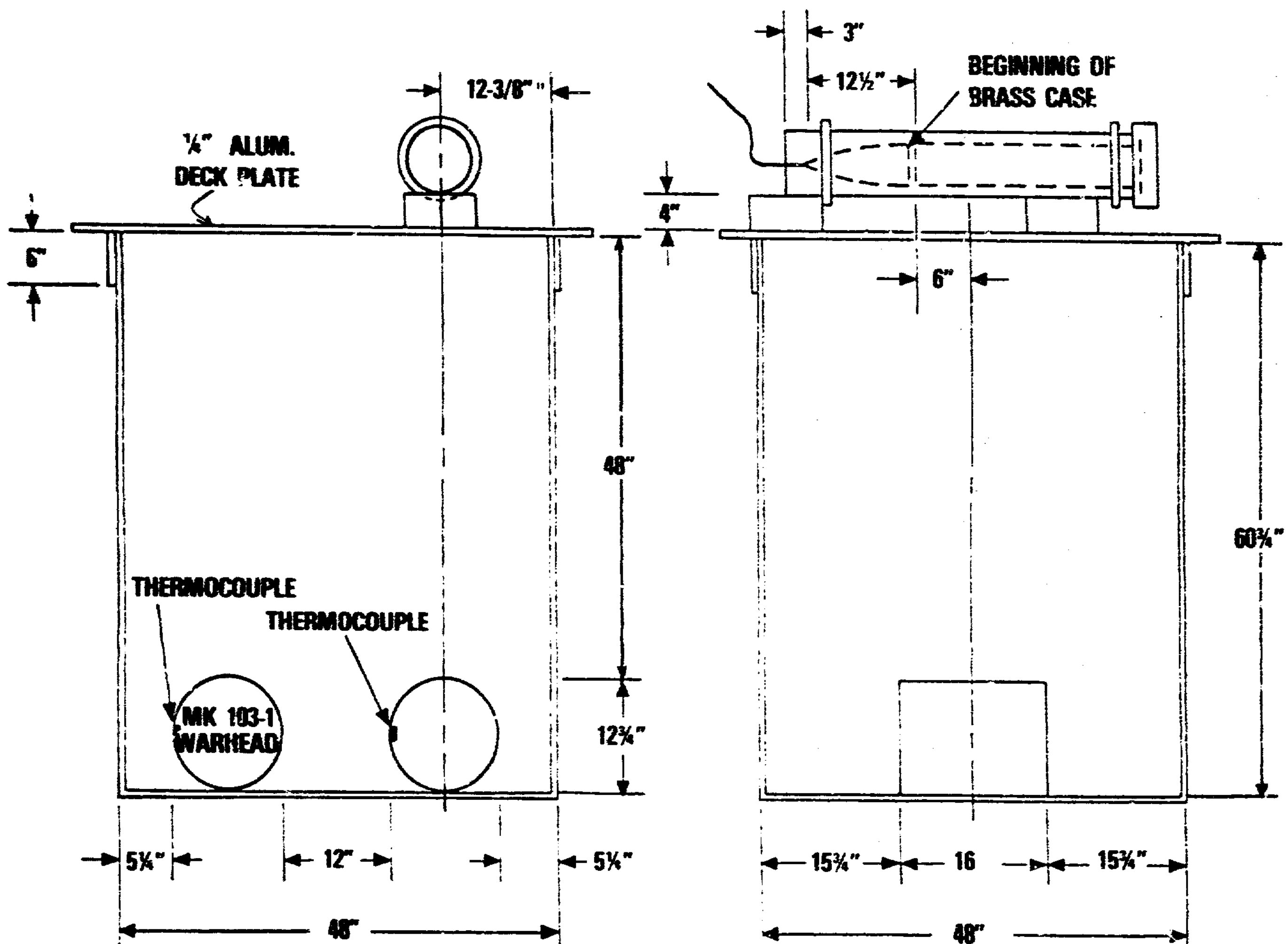


FIGURE 4

TEST WITH TWO CONFINED MK 103 WARHEADS

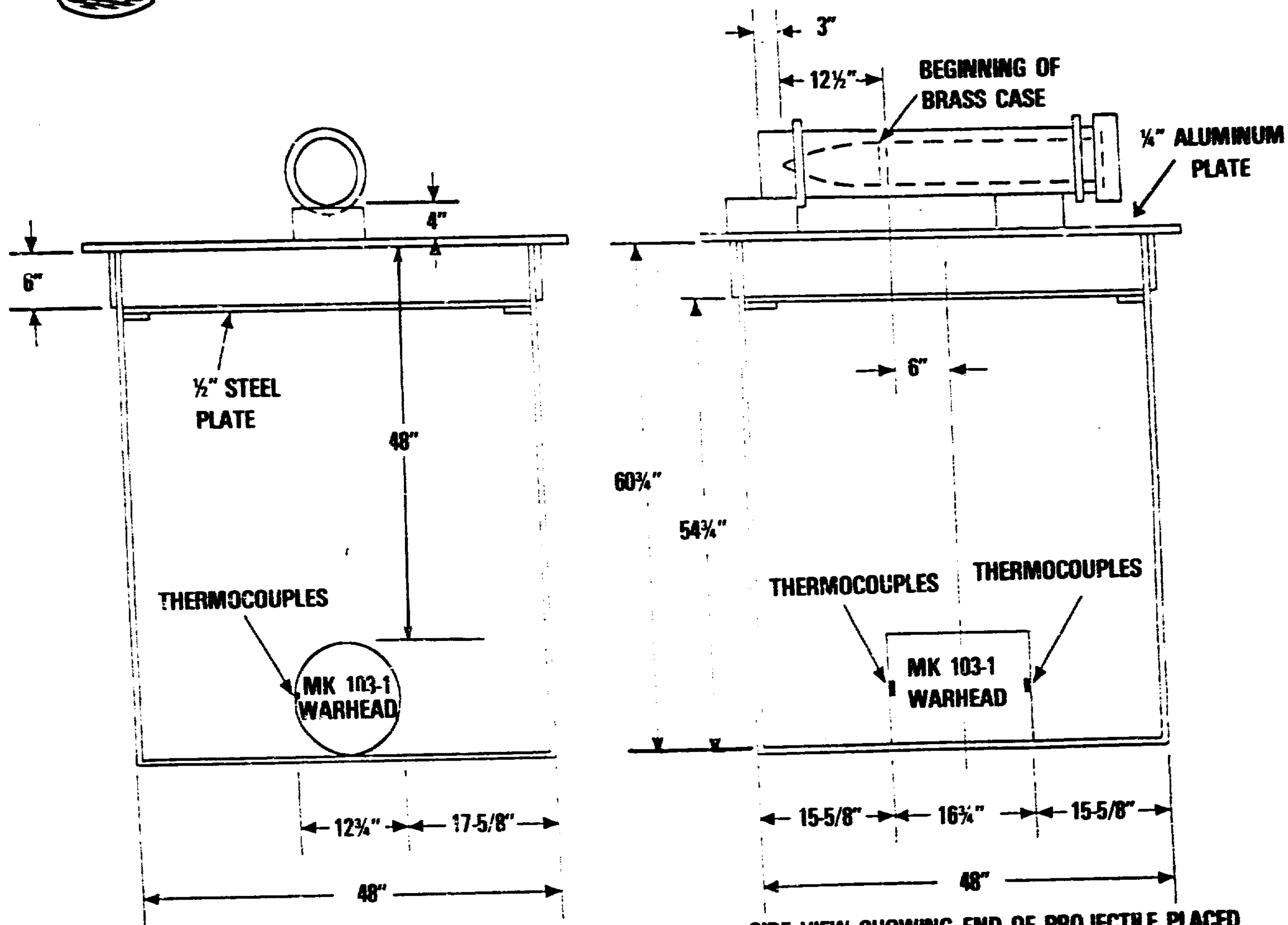


END VIEW OF 76 mm ROUND PLACED ON ALUMINUM SHEET

SIDE VIEW OF 76 mm ROUND WITH END OF PROJECTILE PLACED 18½" FORWARD OF CENTER OF GRAVITY OF THE MK 103-1 WARHEAD

FIGURE 5

GUN MAGAZINE INHIBITOR TEST USING ½" STEEL INHIBITOR PLATE 6" BELOW DECK

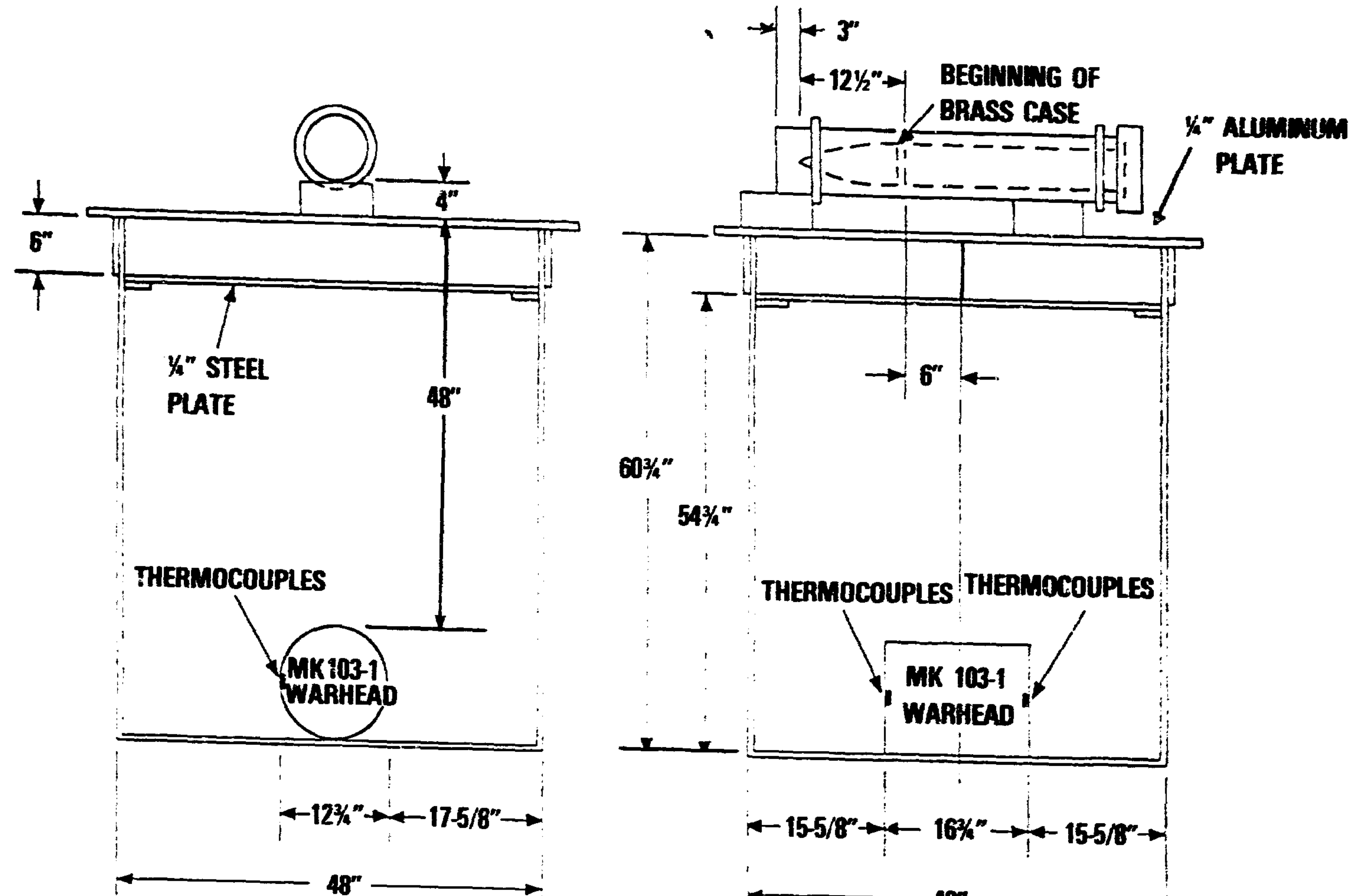


END VIEW SHOWING 76mm ROUND POSITIONED OVER MK 103-1 WARHEAD

SIDE VIEW SHOWING END OF PROJECTILE PLACED 18½" FORWARD OF CENTER OF GRAVITY OF THE MK 103-1 WARHEAD

FIGURE 6

GUN MAGAZINE INHIBITOR TEST USING ¼" THICK STEEL INHIBITOR PLATE 6" BELOW DECK



ENDVIEW SHOWING 76 mm ROUND POSITIONED OVER MK 103-1 WARHEAD

SIDE VIEW SHOWING END OF PROJECTILE PLACED 18½" FORWARD OF CENTER OF GRAVITY OF THE MK 103-1 WARHEAD

FIGURE 7

GUN MAGAZINE INHIBITOR TEST USING ¼" STEEL INHIBITOR PLATE 6" ABOVE DECK

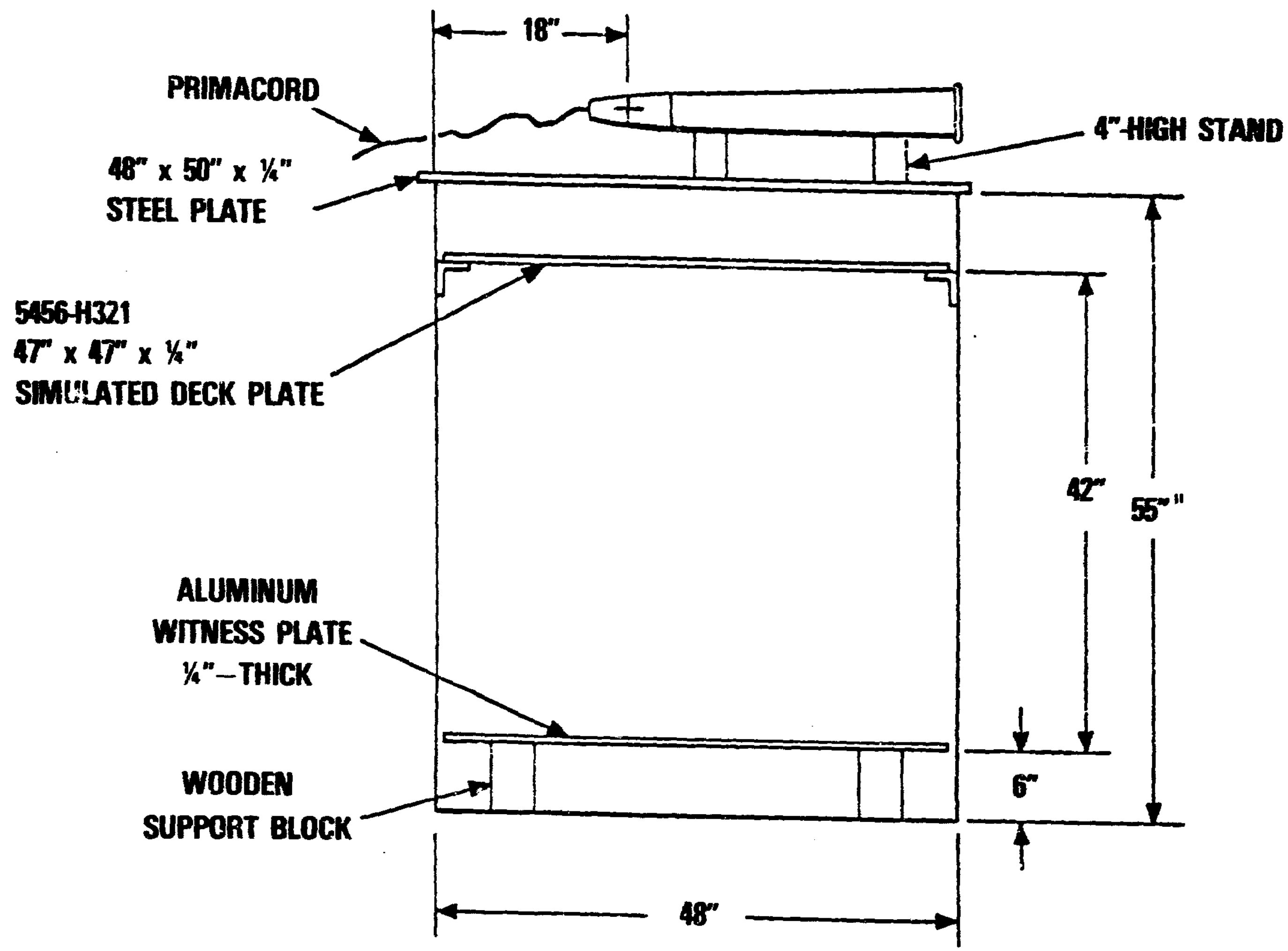


FIGURE 8
TORPEDO STACKING ARRANGEMENT

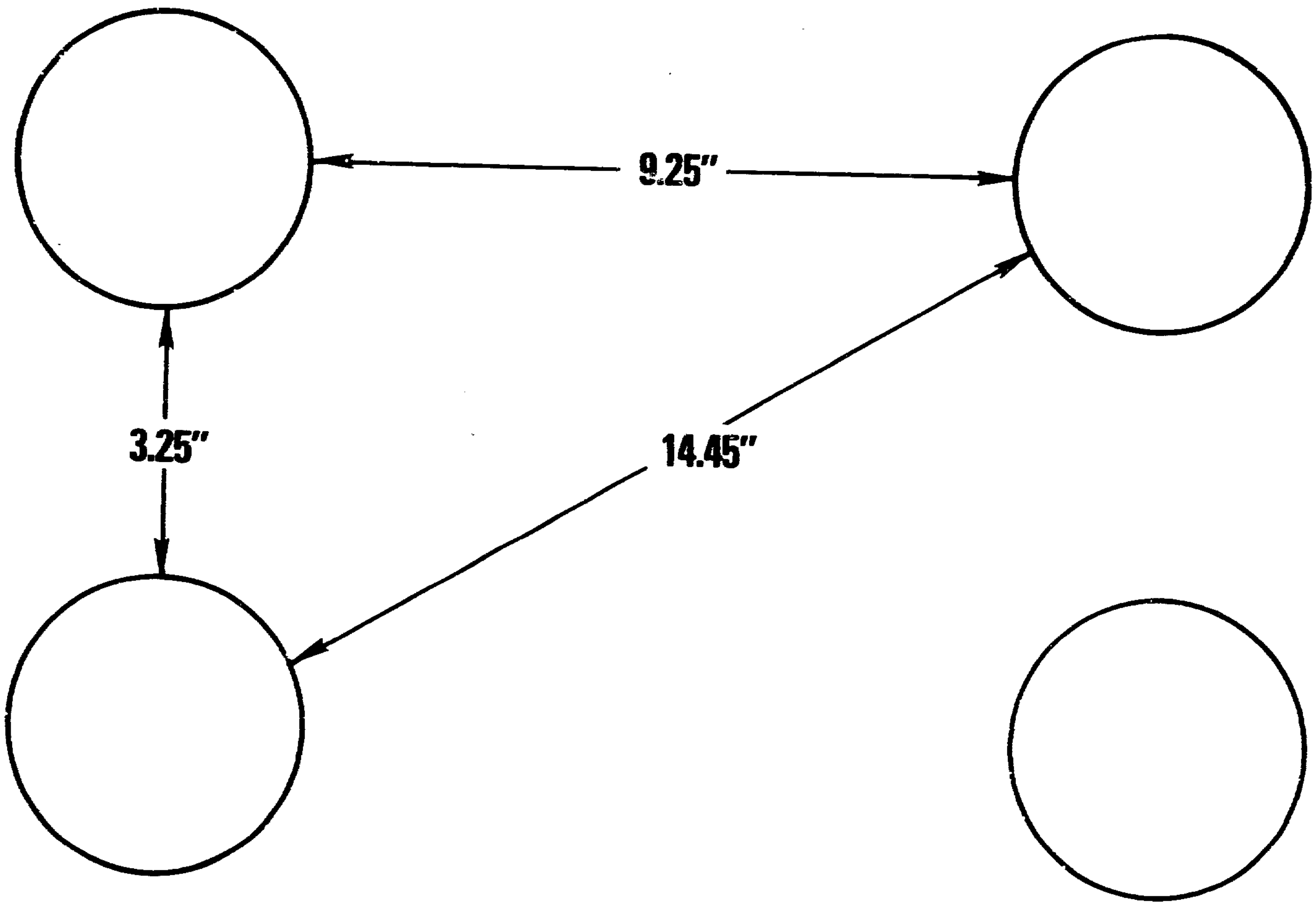


FIGURE 9

TEST SET-UP FOR EVALUATING ¼" STEEL PLATE INHIBITORS

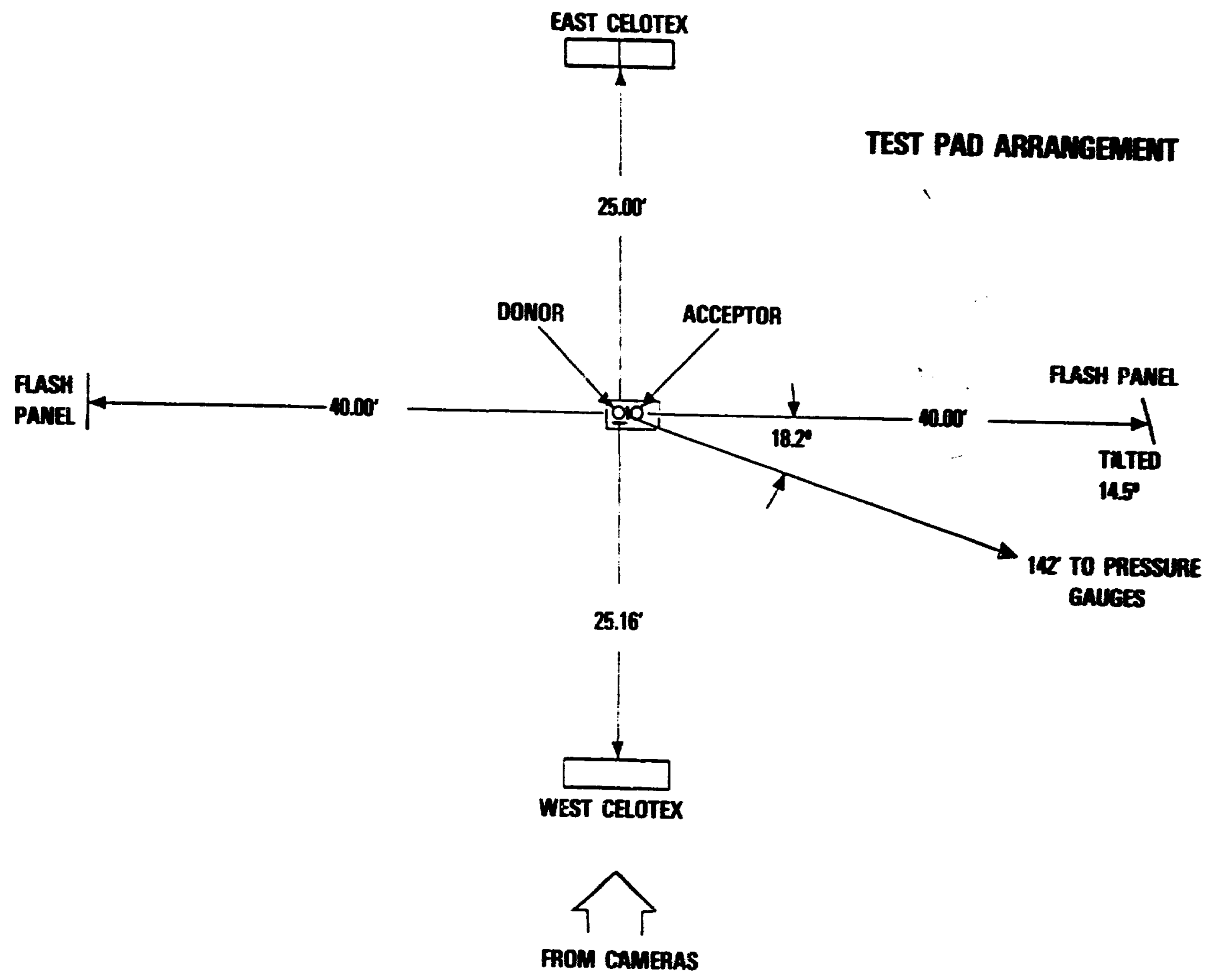
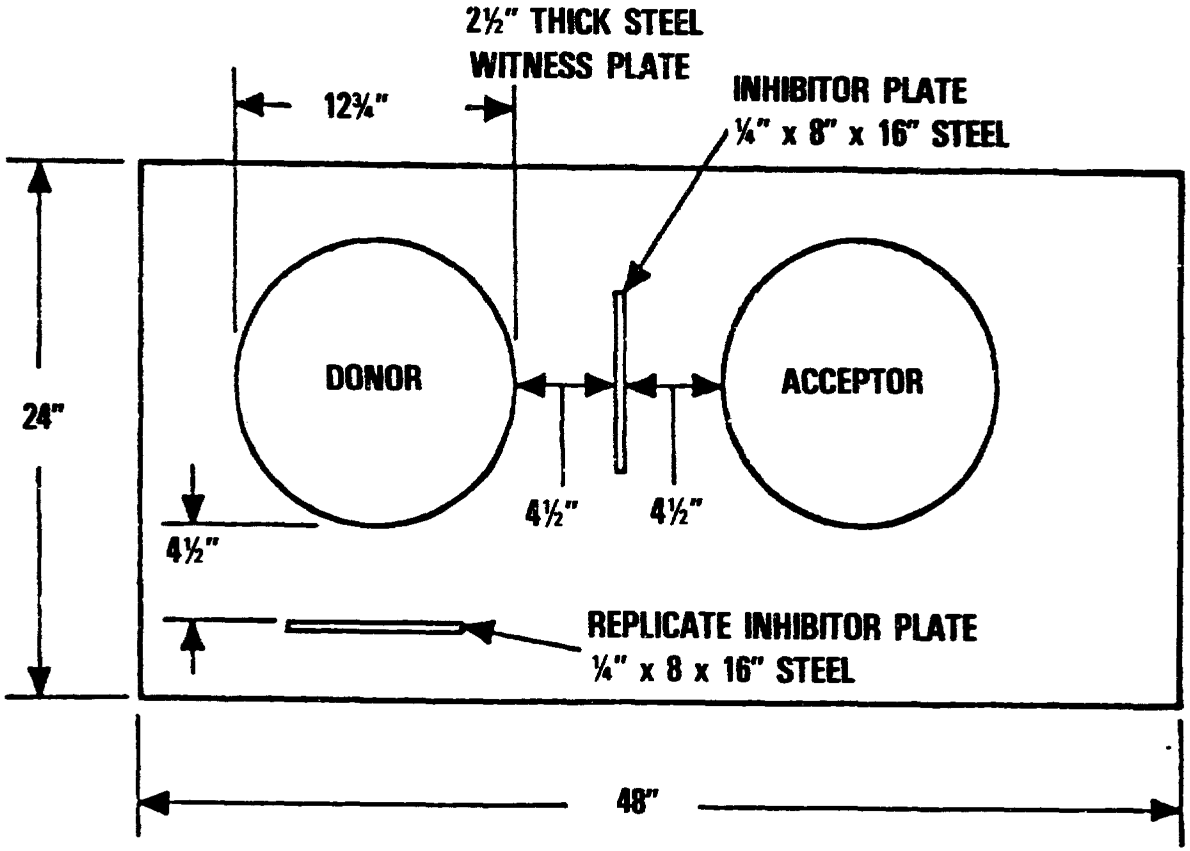


FIGURE 10

CLOSE-UP OF WARHEAD INHIBITOR ARRANGEMENT



PLAN VIEW OF WARHEADS, INHIBITOR PLATE, AND REPLICATE INHIBITOR PLATE

TABLE I
RESULTS OF ¼" STEEL PLATE INHIBITOR TESTS

TEST NO.	WARHEAD SEPARATION (SURFACE TO SURFACE)	RESULTS
1	14"	ACCEPTOR DID NOT DETONATE 1. ONLY ONE HOLE IN WITNESS PLATE 2. MANY HOLES IN DONOR FLASH PANEL — NONE IN ACCEPTOR FLASH PANEL 3. DONOR FLASH PANEL DRIVEN TWICE AS FAR AS ACCEPTOR FLASH PANEL 4. MUCH UNBURNED EXPLOSIVE AND LARGE FRAGMENTS FROM ACCEPTOR RECOVERED
2	3¼"	ACCEPTOR DID DETONATE 1. TWO HOLES IN WITNESS PLATE 2. MANY HOLES IN BOTH FLASH PANELS 3. BOTH FLASH PANELS DRIVEN ABOUT SAME DISTANCE 4. NO LARGE ACCEPTOR FRAGMENTS FOUND 5. ACCEPTOR FRAGS HAD HIGHER VELOCITY THAN DONOR FRAGS
3	9¼"	ACCEPTOR DID NOT DETONATE 1. ONLY ONE HOLE IN WITNESS PLATE 2. MANY HOLES IN DONOR FLASH PANEL — NONE IN ACCEPTOR FLASH PANEL 3. ONE LARGE AND MANY SMALL FRAGMENTS FROM ACCEPTOR FOUND 4. DONOR FRAGS HAVE THREE TIMES VELOCITY OF ACCEPTOR FRAGS 5. SOME UNBURNED EXPLOSIVE RECOVERED

FIGURE 11

SUGGESTED Mk 46 TORPEDO ARRANGEMENT MODIFICATION

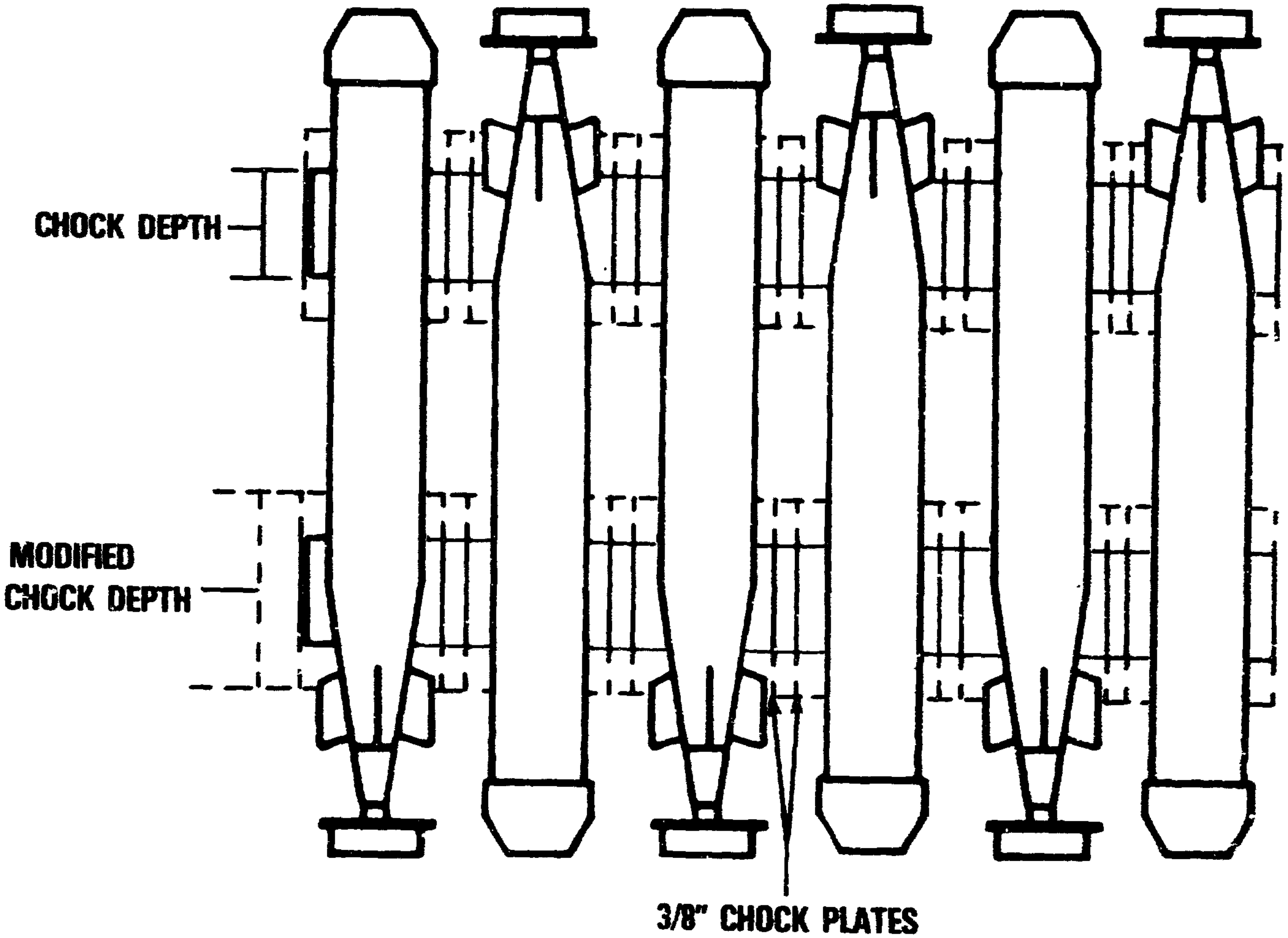


FIGURE 12

TEST SET-UP TO DETERMINE EFFECTIVENESS OF ALUMINUM STOWAGE CHOCKS AS INHIBITORS

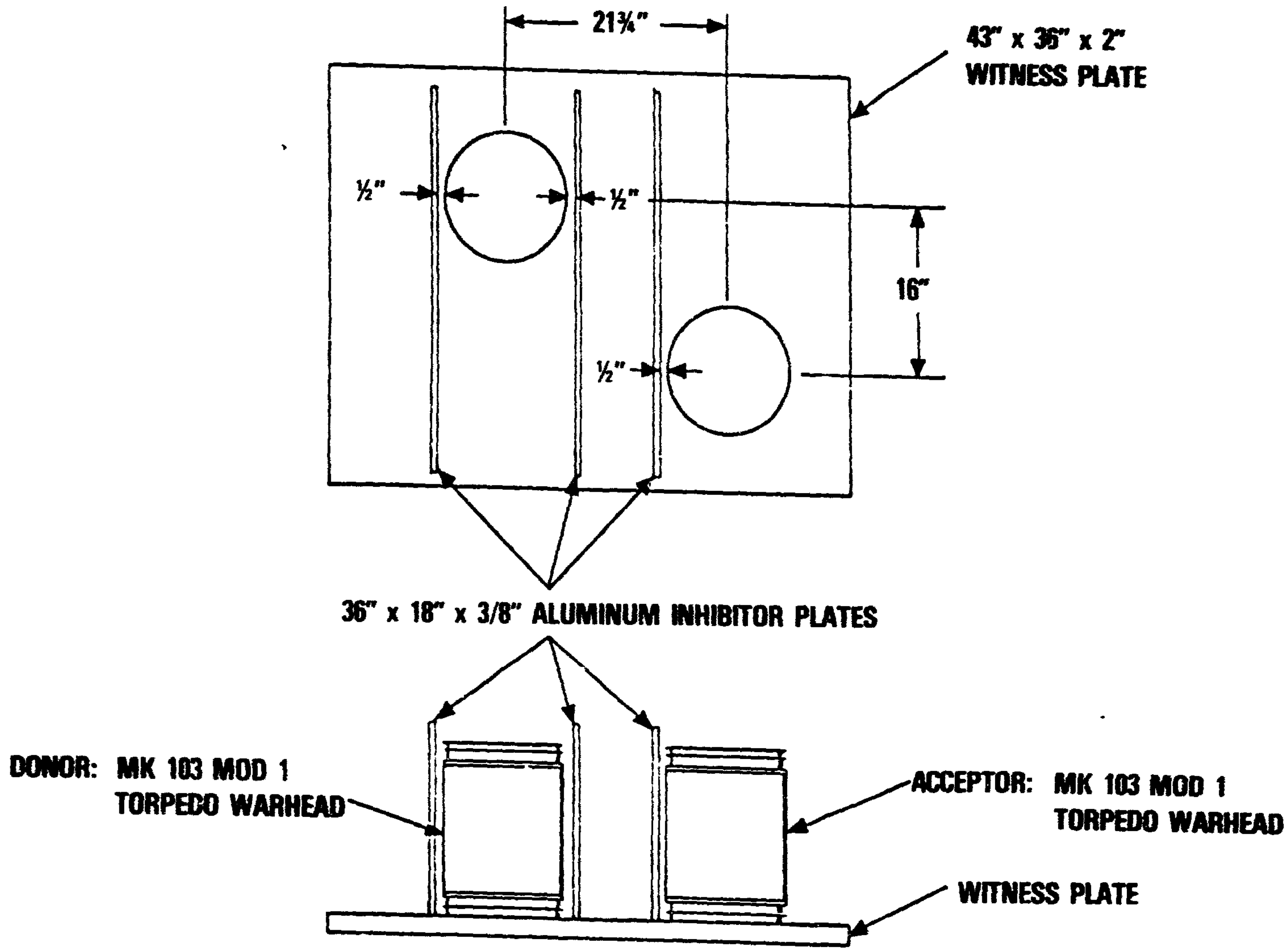


FIGURE 13

BURNING TEST — WARHEADS CONFINED

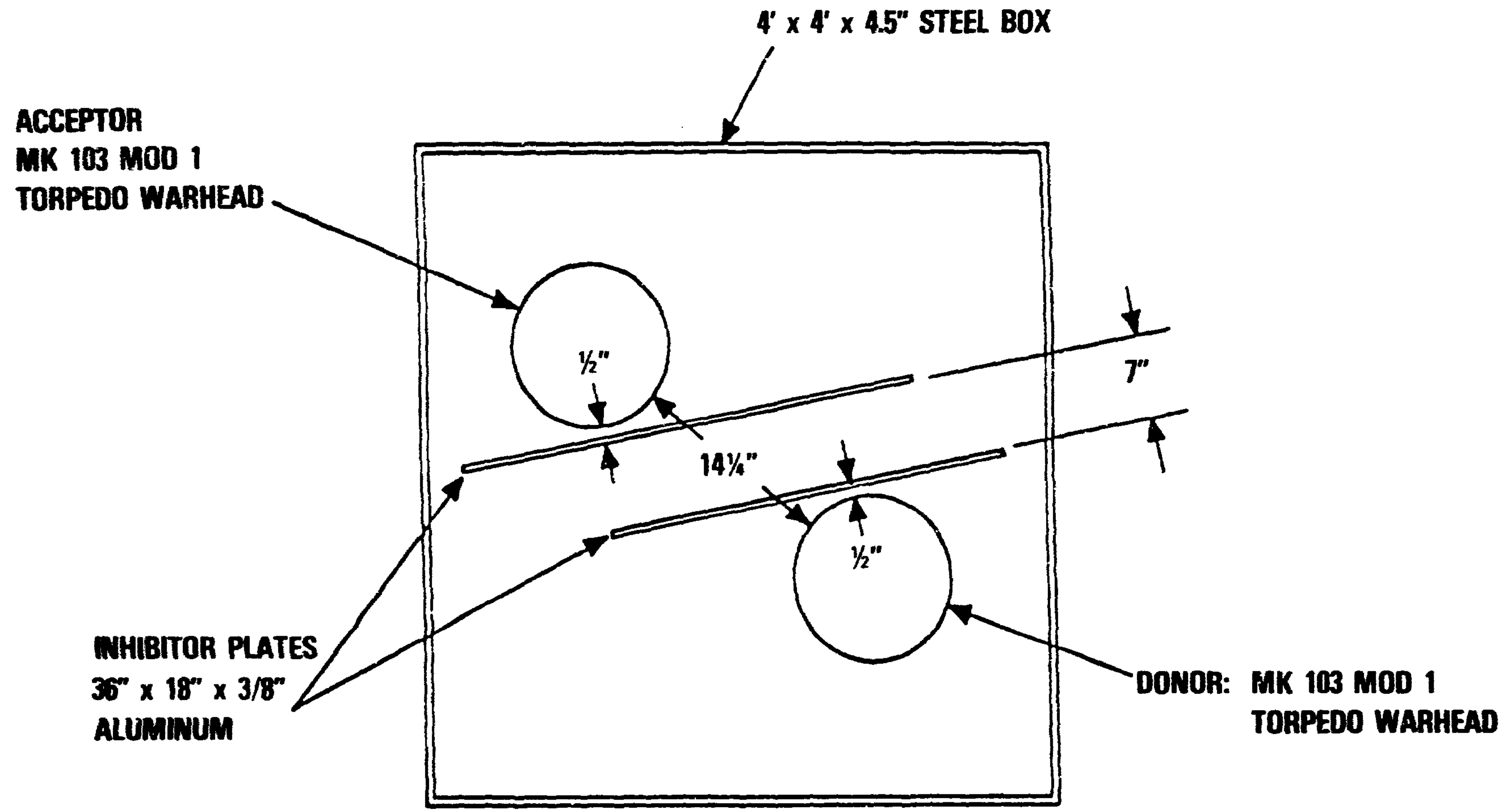
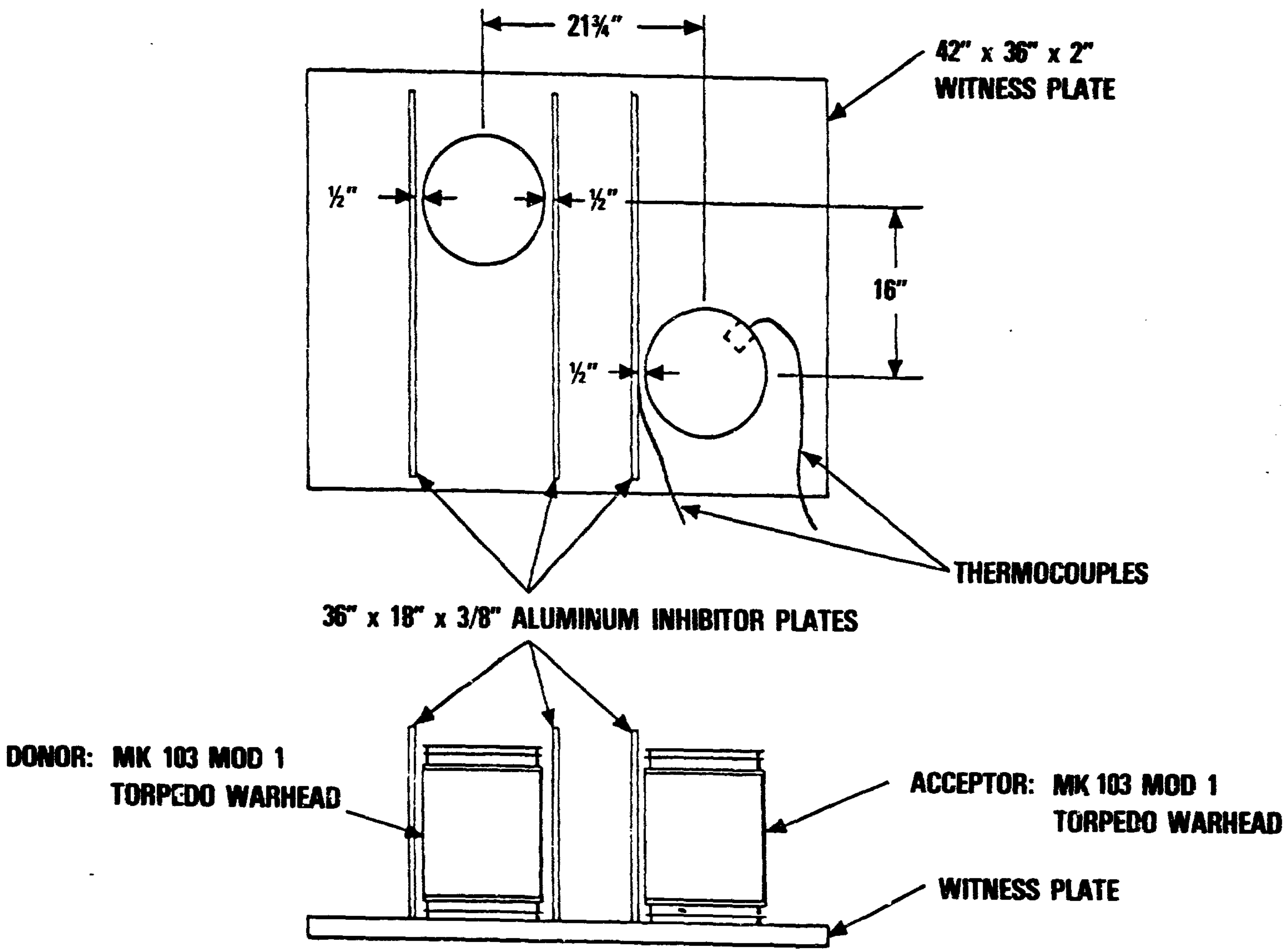


FIGURE 14

BURNING TEST — WARHEADS IN OPEN



ACCIDENTAL TORPEDO DETONATION IN SUBMARINE TENDER WORKSHOPS

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ABSTRACT

Several tests have been conducted to assess the hazards from an accidental torpedo detonation aboard a submarine tender or on the dock alongside. The tests were designed to establish:

1. the likelihood of sympathetic detonation of nearby torpedoes on the pier, in the workshop or in the magazine;

2. blast and fragment hazard ranges outside the ship.

At warhead separations of about 4 feet a 5/16" steel plate was sufficient to prevent sympathetic detonation. A single unconfined warhead outside the ship produces 1 psi side-on blast overpressure at a range of about 500 ft. The density of case fragments produced by an unconfined warhead is less than one hazardous fragment in 600 ft^2 at ranges less than 500 feet from the warhead. Based on these results, the hazard arc around a single unconfined torpedo warhead should be 500 feet.

INTRODUCTION

Torpedo servicing aboard submarine tenders is forbidden in most ports because of the need for conducting unrelated activities near the ships. An acceptable stand-off, specified by regulation, is based solely on Net Explosive Weight (NEW) aboard the ship with no leeway provided to allow for the nature or location of the operation being conducted.

A major objective of the Navy Explosive Safety Improvement Program (NESIP) is to determine acceptable hazard ranges for an explosion in the workshop aboard a submarine tender. If, as anticipated, the ranges are less than those prescribed by regulation, hazard arcs can be reduced.

The overall purpose of NESIP is to establish the Maximum Credible Explosion (MCE) and the acceptable hazard ranges pertinent to various munitions handling situations. Acceptable hazards are defined as follows:

- Less than 1 psi blast overpressure;
- Less than one fragment per 600 ft^2 of collection area with kinetic energy exceeding 58 ft lb.

POTENTIAL TENDER ACCIDENTS

Accidental explosions aboard a submarine tender that will pose serious external threats are assumed to occur either in the workshop or in the torpedo magazine below the workshop. Potential sites are illustrated in Figure 1. Prior tests in the NESIP series (Reference 1) indicate that the MCE for an accident in either compartment can be limited to a single warhead by shielding and judicious placement of warheads. This report explores three aspects of the tender accident scenario:

- Sympathetic detonation in the magazine due to an accidental detonation in the workshop.
- Possible propellant contribution to accident severity.
- Fragment and blast hazard ranges from a single unconfined warhead.

A future test will define the fragment/blast hazards due to a single warhead which detonates confined in the workshop compartment.

WORKSHOP/MAGAZINE ARRANGEMENT

The pertinent areas aboard a typical submarine tender are indicated by heavy lines in Figure 2 and 3. The workshop extends from Frame 36 to Frame 45 on the third deck. The lateral boundaries are the port and starboard hull plates, and the lower boundary is the magazine, about two-thirds of which is below the water line. Five decks separate the workshop from the topmost weather deck.

For a torpedo explosion in the workshop/magazine area, the five decks above, the water below and the compartments and bulkheads fore and aft will absorb or attenuate the blast and fragments projected in those directions. The lateral bulkheads and hull provide less resistance and could provide secondary

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Reference 1 Porzel, F. B. "A Model and Methods for Control of Sympathetic Detonation", 18th Explosive Safety Seminar, San Antonio, TX, Sep 1978.

fragments as well as permit primary fragments and blast to leave the ship. Thus, the primary hazard to surrounding real estate is found off each side of the ship in a fan outward from the center of the workshop.

Two torpedoes can be serviced simultaneously, one on either side of the workshop compartment. Each torpedo is placed about four feet from an inner lateral bulkhead about 35 feet from the other torpedo. External hazards arise if one of the torpedoes explodes during servicing. Sympathetic detonation of the second weapon in the workshop will be prevented by placing each warhead outside the fragment spray of the other. Blast overpressures at 35 feet is not sufficient to cause initiation.

The presence of torpedoes in the magazine below the workshop also must be considered. Those closest to the underside of the deck are shown in Figure 4. If one of the weapons in the magazine detonates as a result of an accidental explosion in the workshop, then the entire magazine load could become involved.

HAZARD TEST GOALS

The test program to date has emphasized studying the effects of the accidental explosion of a single torpedo warhead in the workshop. Tests have been designed to evaluate the possibility of sympathetic detonation of the weapons in the magazine and to measure any fragments or blast ejected from the ship.

The tests are described in groups with pertinent results outlined. Blast and fragment measurements and accompanying predictions prepared for the two simulated magazine tests are then described in some detail.

SYMPATHETIC DETONATION

These tests were conducted with pairs of obsolete torpedo warheads -- one as donor, one as acceptor. For three of the shots the warheads were mounted vertically with nothing between them; for skin-to-skin separations of 8', 16' and 32', the acceptor detonated sympathetically.

Four other tests were fired, each with a steel plate midway between the warheads, which were placed 40" apart. No sympathetic detonation occured. On one shot the warheads were mounted horizontally, one above the other, with a 5/8" steel plate between them. Several large pieces of the plate were recovered which were formed to the cylindrical shape of the acceptor. There were no fragment marks on the concave side of the plate pieces. The convex sides of the plate pieces showed evidence of many fragment strikes, but there were no penetrations. About 100 lb of acceptor explosive were recovered around ground zero following the shot (Reference 1).

For the remaining three shots, the warheads were mounted vertically on witness plates, with a 5/16" steel plate midway between donor and acceptor. The set-up for these three tests is shown in Figure 5. In the tender accident scenario, the warheads would be somewhat more than 40" apart and there would be at least a 5/16" deck plate midway between donor and acceptor. These tests indicate that the explosion of a single warhead in the workshop will not cause sympathetic detonation in the magazine.

The tests also indicate that mass detonation in the magazine can be avoided by providing sufficient separation and modest shielding between warheads. Separation can be accomplished by downloading the magazine and reversing alternate weapons head-to-tail. With separation increased sufficiently, judicious location of shielding plates will ensure that mass detonation will not occur even if one warhead explodes.

CONFINED OTTO FUEL

Two shots were fired to determine the effect of projectile fragments on an all-up torpedo (Reference 2). For each shot a torpedo was placed in a leak tight steel box partially buried in the ground, as shown in Figure 6. A projectile on a ¼" aluminum deck 36" above the top surface of the torpedo was statically detonated. On one test, the fragment spray intersected the torpedo fuel tank; on the other test the fragment spray struck the torpedo warhead. In both cases fire broke out in the steel-lined excavation, but no detonation occured.

SIMULATED MAGAZINES

Two tests involving torpedoes in a simulated workshop/magazine have been completed. These tests were designed primarily to establish the probability of causing sympathetic detonation in the magazine stores when a warhead is detonated in the workshop. A third test, soon to be conducted, will provide information on ship structure fragmentation.

On each of the tests, a donor warhead was placed on an aluminum pipe rack so that its lower surface was 21" above a 5/16" steel plate supported by I beams simulating the workshop deck supports aboard ship. 30" below the simulated deck acceptor warheads were placed on cantilevered supports similar to those in the ship's magazine. Steel sheets were placed on the ground surface under the acceptors to provide a hard surface similar to those found aboard ship.

For the first test, four acceptor warheads were placed as shown in Figure 7 to simulate the four warheads in the magazine closest to the donor. They were enclosed in an excavation approximately 24' by 30' by 12' deep to simulate the confinement provided by the magazine.

For the second test the entire model was above ground level (see Figure 8). Confinement for either of the warheads was considered unnecessary. A single live acceptor warhead was placed below the deck. Below the acceptor a 5' length of steel pipe with the same diameter as the warhead substituted for another warhead in the magazine. In addition to the warheads, a fully loaded fuel tank was placed behind the donor warhead, separated from it by an electronics control package. Aluminum flash panels placed at 30' and 70' from the donor in the side-spray of its fragments provided a measure of initial case fragment velocity.

Reference 2 Martin, G. H., "The Explosive Hazard Presented by the Torpedo Magazine of a Guided Missile Frigate (FFG Series) During Pierside Topping-off Operations", 19th Explosive Safety Seminar, September 1980, Los Angeles, CA

Each test was instrumented with a string of airblast gages, high speed cameras looking from various angles, ionization probes in the exploder wells of the acceptors and a 2" thick, 3' square steel witness plate. Fragments were collected from a recovery pad at ranges from 500' to 1000' at angles between 75° and 105° from the nose of the donor warhead. Large fragments were mapped individually with a surveyors transit at closer ranges.

On neither shot did any sympathetic detonation occur. In both cases, explosive from the acceptors was scattered and burned for about an hour after shot time. All witness plates were recovered; none showed evidence of detonation. The film records did not show evidence of more than one detonation and no pulses were received from the ionization pins in the acceptors.

Figures 9, 10, and 11 illustrate the second test. Figure 9 shows the operation of loading the liquid propellant in the tank portion of the donor. At the time the photograph was taken, the witness plate had not been mounted on the acceptor. The first two of the six gage stations appear in the lower portion of the picture.

Figure 10 was taken from one of the high speed cameras aimed at the same side of the model shown in the previous photo. Scale is indicated by the outline of the donor warhead and support stand on the photograph. Burning acceptor explosive can be seen falling out of the explosion cloud 2.083 sec after the donor was detonated. Some of the explosive remained burning on the ground for about an hour after shot time.

Figure 11 shows ground zero after the shot. The four corner supports of the model remain in place but are bent inward; there is negligible cratering. Two of the many clumps of burned explosive are indicated on the ground.

<u>SHOCK OVERPRESSURES</u>. Side-on overpressure measurements and calculations (both scaled to sea level) are shown in Figure 12. The line represents the calculations (Reference 3) and the points represent average pencil gage measurements at each range on the second test. The calculation was made for a surface burst on a smooth horizontal surface which slopes down from the donor warhead out to about midway between the third and fourth gage stations; the three gage posts farthest from the donor were mounted above a smooth, flat and slightly dusty surface. One of the two gages at the closest in station failed; for all other stations the values plotted are the average of two measurements. Comparison of the data with the calculation indicates that only one warhead detonated.

The one psi level occurs at about 500 ft, indicating that, from the point of view of blast hazard, an unconfined torpedo warhead presents an acceptable hazard beyond that range.

<u>CASE FRAGMENTS</u>. On the second shot the first fragment strike on the flash panel at 70 ft from the donor was seen on a high speed film at about 7.7 ms after detonation. Thus, the average velocity of this fragment was nearly 9000 ft/sec. This is a minimum value for the initial velocity of case fragments from the donor warhead.

Ref 3 Porzel, F. B. "Introduction to a Unified Theory of Explosions (UTE)", NOLTR 72-209, 14 September 1972.

To arrive at a particular range, the fragment initially projected at a high angle from the horizontal will travel a greater path length than the fragment initially projected at a low angle. A low angle fragment will in general have a higher residual velocity than one of the same mass initially projected at a higher angle. This difference in arrival velocity at the target area occurs because drag forces act on the low angle fragment over a shorter path length than on the high angle fragment. Thus, for a given mass, the kinetic energy carried by the low angle fragment will be greater than that carried by the high angle fragment.

Trajectory calculations were made for a range of fragment weights and initial projection angles. Fragments were assumed to be aluminum cubes for purposes of the calculation. A range of initial angles (high and low) can be determined for trajectories which terminate within a specific increment of range from the donor. Assuming a uniform angular distribution of case fragments around the axis of the donor, the angle spread for low and high initial angles for a given ground range increment and fragment mass can be found. The ratio of the low angle spread to the high angle spread is assumed to be the ratio of hazardous to non-hazardous fragments of that mass in a given radial zone.

Range vs angle calculations for a 10 gm fragment are displayed in Figure 13. Initial velocity of the fragment was taken to be 9000 ft/sec. The calculation of the hazardous/non-hazardous fraction is shown on the figure.

This method was used to determine the number of hazardous fragments among those picked up from the recovery pad after the second shot. The total number of fragments recovered in each of the 25 zones is shown in Figure 14; 98.5% weighed less than 25 grams, and only 2 of the 568 weigh ed more than 65 grams. The total number and the number of hazardous fragments per 600 ft^2 in each zone are shown in Figure 15. The number of hazardous fragments in each 100 ft. wide circumferential strip on the recovery pad is shown in Figure 16. The number of hazardous fragments decreases with range, and nowhere in the recovery area does the areal density approach unity.

Thus, case fragments from an unconfined warhead do not pose an unacceptable hazard beyond 500 ft.

CONCLUSIONS

Each of the tests described in this report has provided information about one or more of the explosion safety hazards associated with handling torpedoes aboard a submarine tender in port. Based on the results in hand, the following conclusions can be drawn:

Single Unconfined Warhead Outside the Ship

1. Propellant contribution

   - torpedo propellant may burn vigorously, but will not detonate in the tender accident scenario.

2. Blast and fragment hazards

   - 1 psi side-on overpressure will be found at or inside the 500 ft range.

   - one hazardous fragment per 600 ft^2 of horizontal area will be found well within the 500 ft range.

3. Hazard arc

   - the preceding observations imply that for a single unconfined warhead outside the ship, the hazard arc should be 500 ft.

Sympathetic detonation

- Detonation of a single warhead in the workshop will not induce subsequent detonations of:

   - warheads in the magazine

   - another, properly oriented, warhead in the workshop.

- Mass detonation in the magazine will not occur if the weapons are spaced, oriented and shielded properly.

PLANS

An additional test is in preparation. For this test a warhead will be detonated inside a 1/2 scale mock-up of the tender workshop. Airblast and ship structure fragment ranges will be determined. Upon completion of this final test, a formal report will assay the minimum hazard arc around a submarine tender should a torpedo detonate accidentally within the workshop compartment.

The next situation to be addressed will be the synergistic effects of an accidental detonation aboard the tender on the weapons aboard submarines nested against the tender. The obverse will also be studied: the effects of an accidental explosion aboard one of the nested submarines on the tender load. The requisite hazard arc around this ship unit complex, for either source, will be determined.

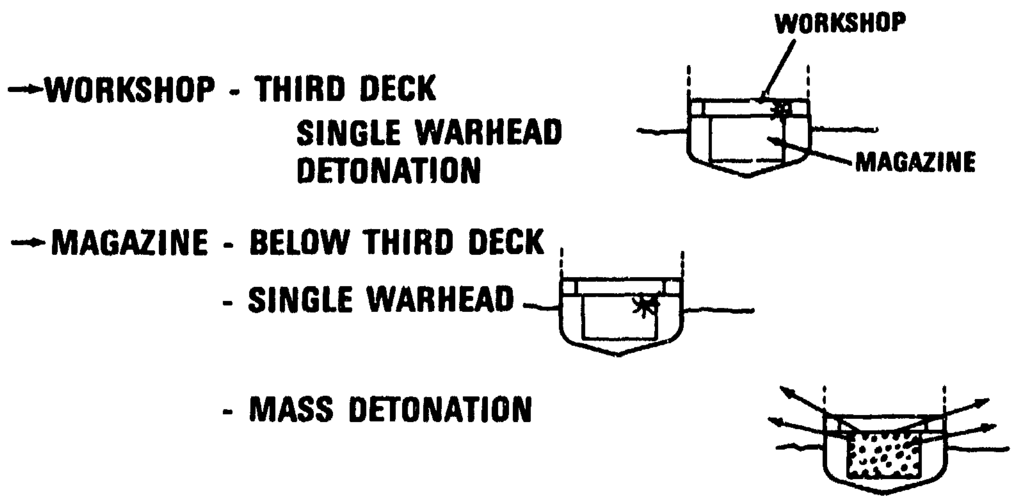


Figure 1 Potential Accidents

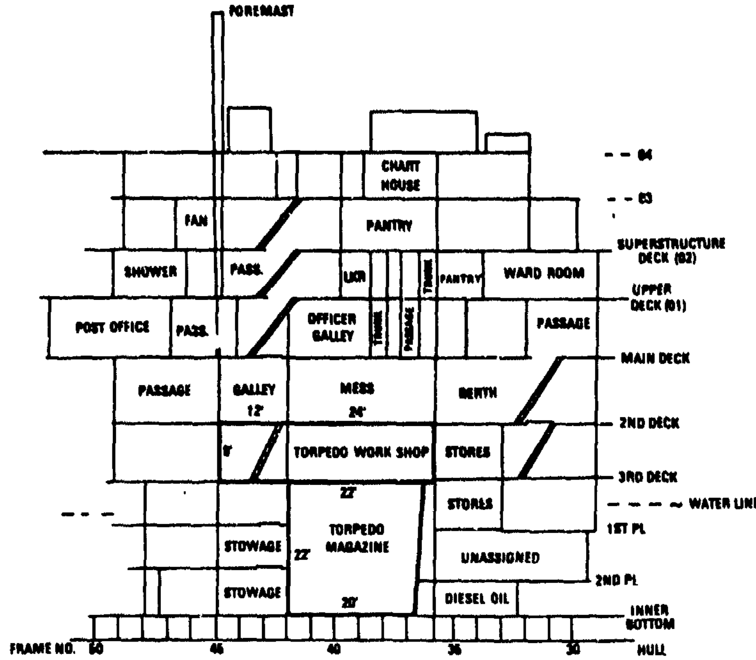


Figure 2 Tender Elevation at Center Line

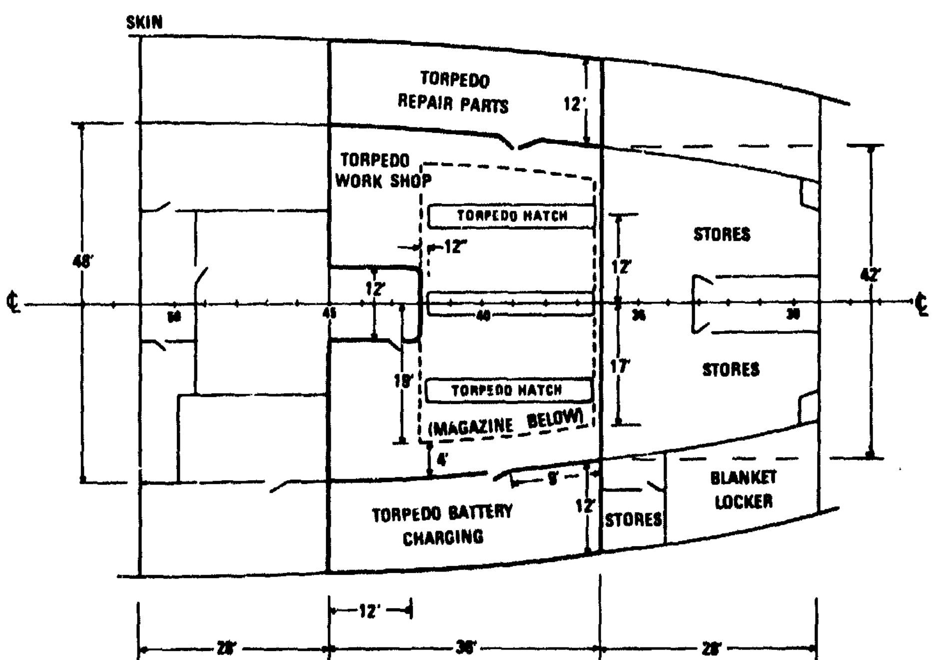


Figure 3 Plan View of Workshop Deck

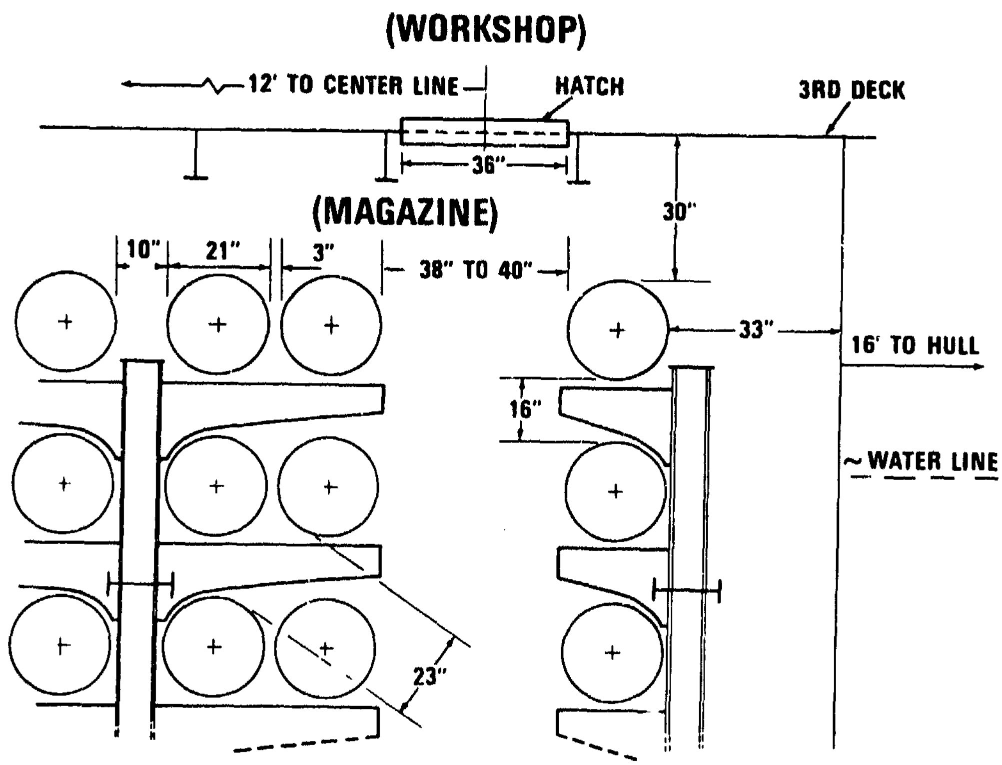


Figure 4 Magazine Torpedo Stowage,
Port Side Looking Aft

DETERMINE SHIELD THICKNESS REQUIRED AT STAND-OFF TYPICAL OF SHIPBOARD WORKSHOP/MAGAZINE CONFIGURATION:

RESULT: NO DETONATION IN THREE TESTS

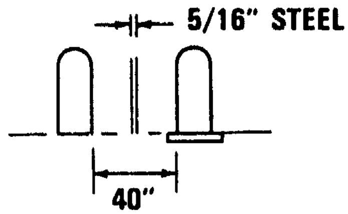


Figure 5 Sympathetic Detonation Test Setup

RESULT: FUEL BURNED; NO WARHEAD OR FUEL DETONATION

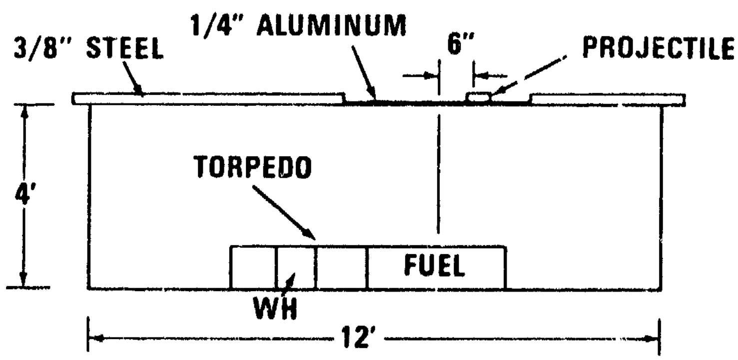
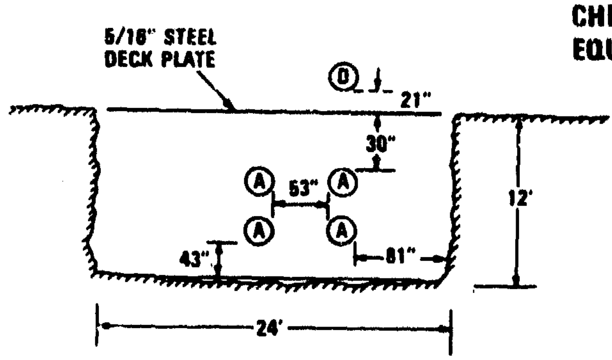


Figure 6 Confined Otto Fuel Test Setup

PURPOSE: DETERMINE HOW MANY ACCEPTORS DETONATE

CHECK OUT DIAGNOSTIC EQUIPMENT



RESULT: FIRE CONSUMED 4 ACCEPTOR WARHEADS

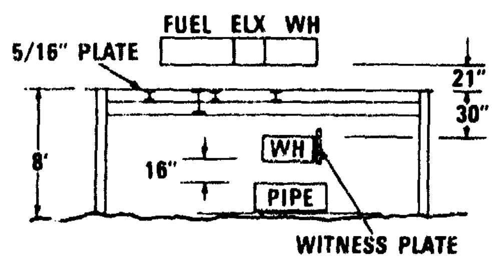
NO SYMPATHETIC DETONATIONS IN ACCEPTORS

OVERPRESSURE ~ 10 PSI AT 120 FT

Figure 7   First Simulated Magazine Test

PURPOSE: COLLECT FRAGMENT AND BLAST INFORMATION

DETERMINE WHETHER THE OTTO FUEL REACTS OR THE ACCEPTOR WARHEAD DETONATES



RESULT: FUEL SCATTERED; NO FIRE OR OTHER REACTION

NO SYMPATHETIC DETONATION IN ACCEPTOR

SHOCK OVERPRESSURE 1 PSI AT R = 500 FT

1 HAZARDOUS FRAGMENT/600 FT^2 INSIDE 500 FT

Figure 8   Second Simulated Magazine Test

Figure 9   Setup for Second Test

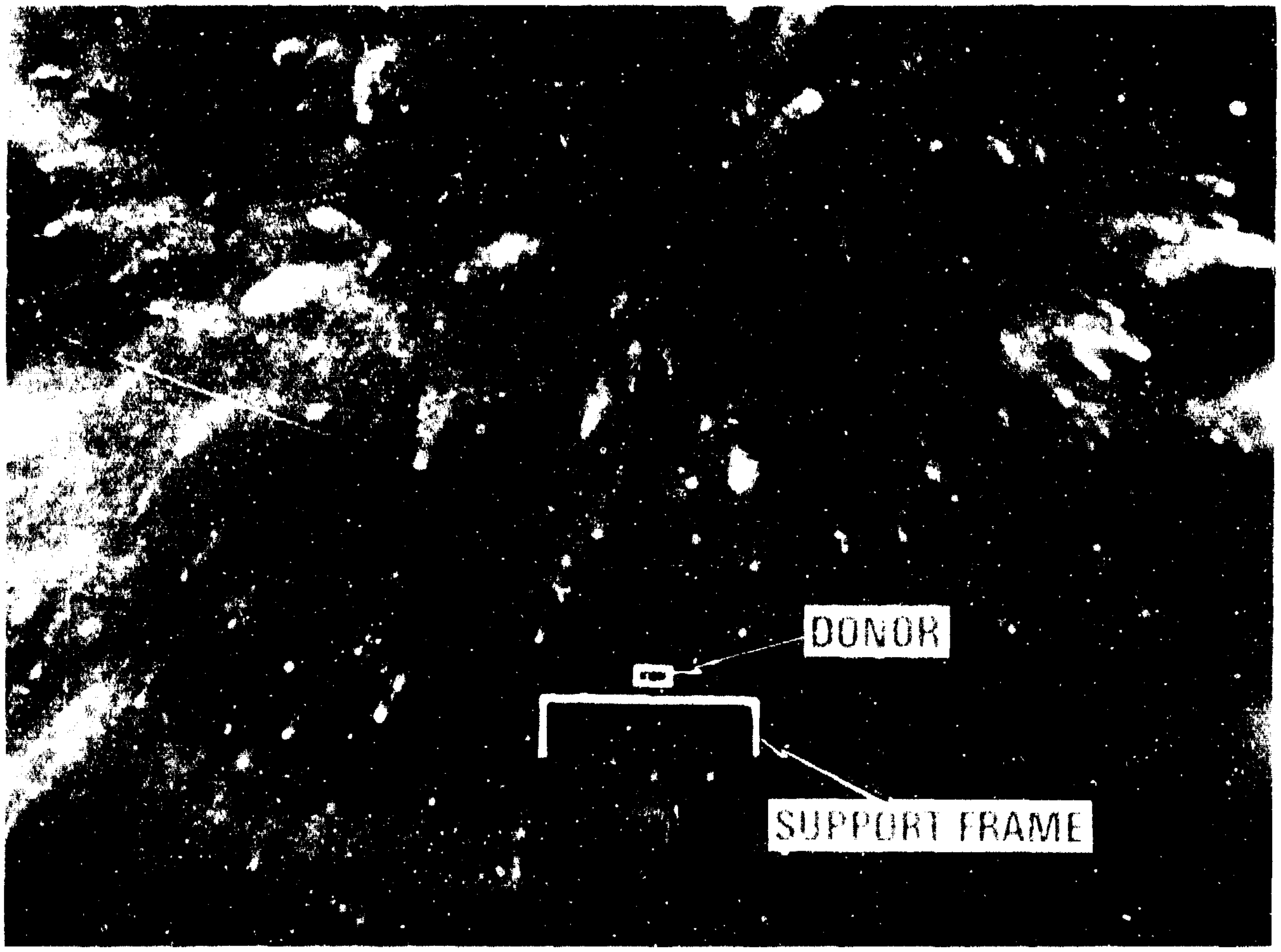


Figure 10 2.083 Sec after Detonation,
Second Test

Figure 11 Result of Second Shot

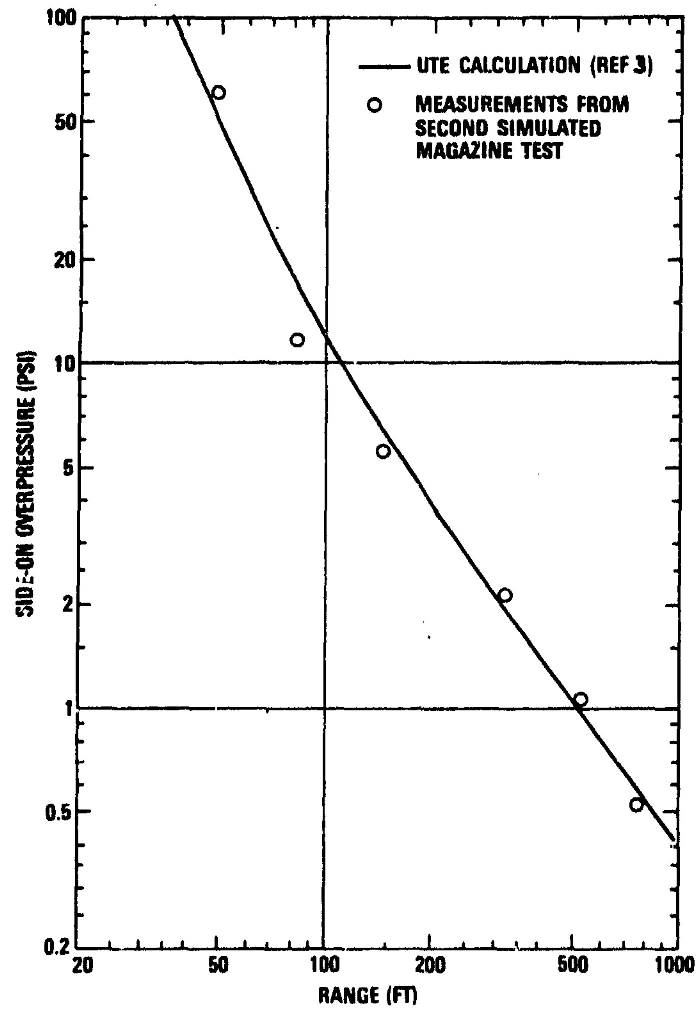


Figure 12 Side-on Overpressures Scaled to Sea Level

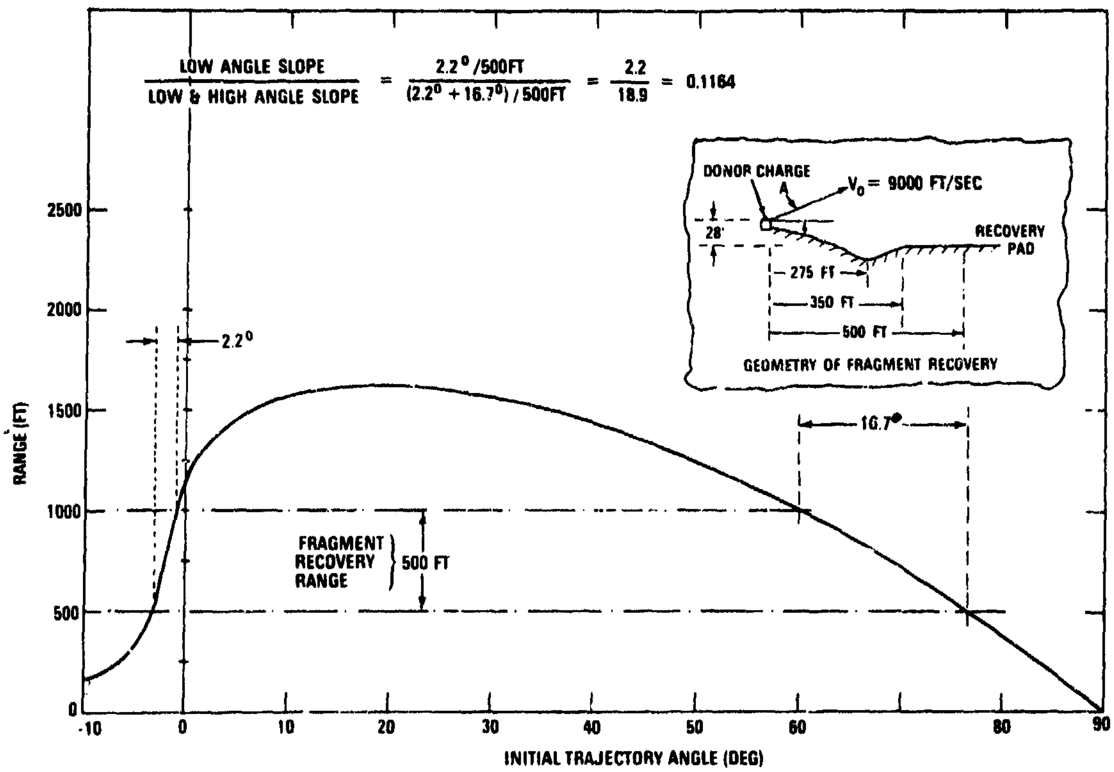


Figure 13 Calculated Range vs Initial Angle for 10 gm Aluminum Cubes

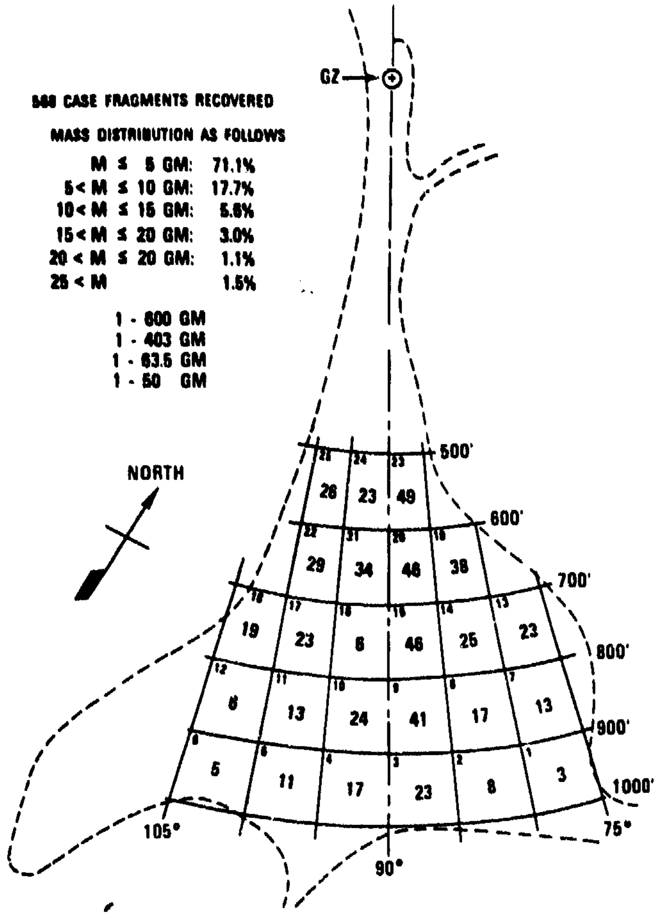


Figure 14 Fragment Recovery
Second Simulated Magazine
Test

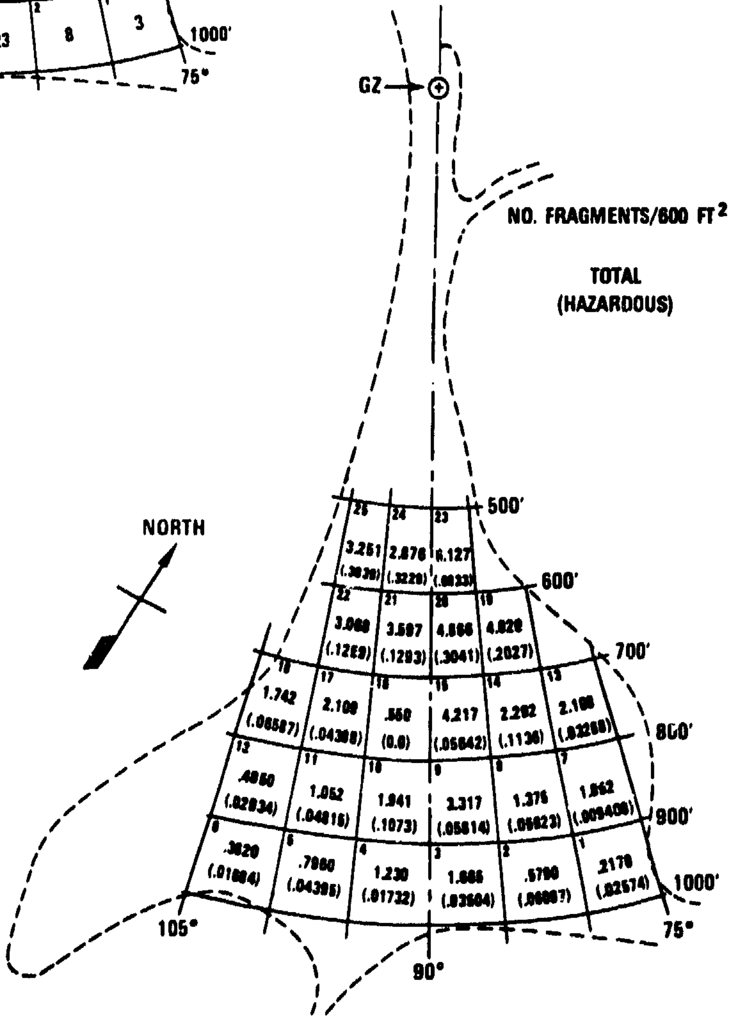


Figure 15

Fragment Areal Densities

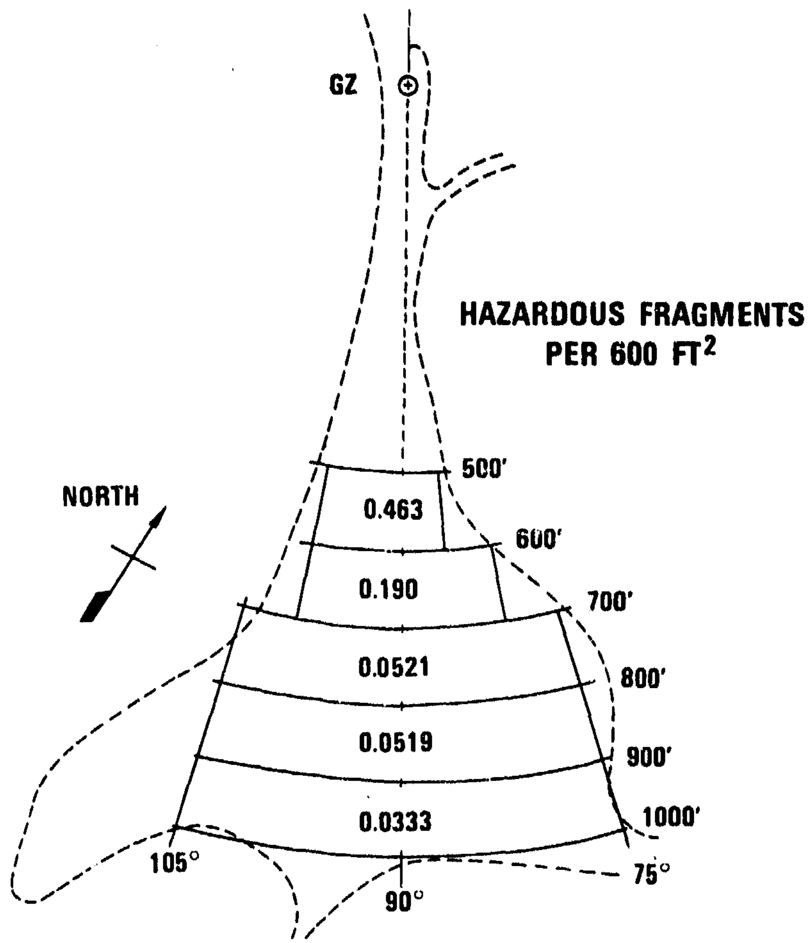


Figure 16 Areal Density of Hazardous Fragments

DETERMINATION OF SAFE HANDLING ARCS AROUND NUCLEAR ATTACK SUBMARINES

by

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Naval Surface Weapons Center

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ABSTRACT

As part of the Navy Explosives Safety Improvement Program (NESIP), an experimental and analytical program has been conducted to determine the explosives safe handling arc around an attack class nuclear submarine during pierside topping off operations. As part of the program, the Maximum Credible Event was determined for the pierside scenario, and from this a Net Explosive Weight of up to 17,200 pounds (TNT equivalent) was calculated, should an explosive incident occur. The problem was studied with models of two sizes: 1/39.6-scale and 1/6-scale. The parameters studied included airblast, fragmentation, underwater pressures, and the dynamics of model break-up and motion. Comparisons are made between the two scale sizes (1/39.6 and 1/6), and predictions and conclusions are made for the full-sized submarine.

BACKGROUND

The work reported herein was conducted as part of the Navy Explosive Safety Improvement Program (NESIP), whose goal can be stated as "the development of analysis and testing programs to obtain realistic data in regard to explosive hazards which may be experienced in Navy ship berthing ports ...".[1]

The Quantity-Distance (Q-D) tables call for a hazard arc of 1250 feet when up to 30,000 pounds of fragmenting munitions are being handled. Only operations essential to this task are permitted within this arc. But at many ports, this arc encompasses many types of normal base activities. The 1250 foot arc is also applied to any quantity of fragmenting ordnance below 30,000 pounds, unless a specific safe handling arc has been established for that ordnance item or scenario.

What defines a safe handling arc? By DDESB definition:

(1) hazardous airblast is defined as an overpressure of 1 psi or greater

(2) hazardous fragments are those having impact energies of 58 foot-pounds or greater

(3) hazardous fragment densities are those areal densities which exceed 1 hazardous fragment per 600 square feet.

Thus, a safe handling arc defines the limits of an area containing neither hazardous airblast nor hazardous fragment densities.

THE PROBLEM

Our problem is to determine the airblast and fragment hazards generated, should an explosion occur in the torpedo compartment of an attack submarine, during pierside topping-off operations. In addition, determine the underwater shock hazards posed to nearby ships by such an explosion.

Tests and analyses have determined that the Net Explosive Weight (NEW) for this scenario can be up to 17,200 pounds (TNT equivalent).

A closely-coupled analytic and experimental approach was followed, thus providing a broader and more reliable fund of information than by either a theoretical or experimental approach alone. The experiments were guided strongly, but not completely, by the NESIP Technology Base, as developed by Porzel and reported elsewhere in the present symposium.[2] Among the topics considered in the analyses and which are implicit in the program were the following:

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[1] Petes, J., "The Navy's Explosive Safety Improvement Program for Pier Side Munitions Operations", Minutes of the Eighteenth Explosives Safety Seminar, Department of Defense Explosive Safety Board, 12-14 September, 1978, Vol. II.

[2] Porzel, F. B., "Technology Base of the Navy Explosive Safety Improvement Program", Minutes of the 19th Explosive Safety Seminar, Department of Defense, Explosive Safety Board, 9-11 September 1980.

(1) Initial Yield of Plastic Bonded Explosives versus conventional explosives used in the testing,
(2) Pressure and Impulse loading on the hull
(3) Failure modes, including quantitative criteria for fragmentation, hull rupture, and "break & tear" failure
(4) Role of interior equipment with regard to waste heat dissipation and channelling of energy
(5) Areal fragment distributions from the catastrophic failure of the hull, and
(6) Pressure-distance relationships near 1 psi.

In order to delineate between the experimental results and their interpretation, the present paper will emphasize the experimental results in their own right, with as little reference to the analysis as is necessary.

As the onset of the program, the question arose: "What is the failure mode of the submarine?" Does it behave like a bomb case and fracture into many small pieces, or does it behave like a pressure vessel and fracture into a small number of large pieces To resolve this question and to verify and extend the preliminary analyses, an experimental effort was begun. It was obvious immediately that testing in full scale would be prohibitively expensive and highly impractical. It was decided to study the problem "in miniature", using sub-scale models. A scale size of 1/39.6 was finally arrived at for our basic model. In this size, the model is small (10" diameter X 30" long) and the scaled explosive weight is under 0.5 pounds. This small size facilitates testing both in bombproofs and in free air.

One 1/6-scale model (5.5 feet in diameter X 17 feet long) was also available from the David Taylor Naval Ship Research and Development Center. It was decided to use this model to try to verify some of the scaling procedures developed in the smaller scale.

THE TEST PROGRAM

The test program was divided into three phases (I, II, and III), with each phase having a different emphasis. Phase I utilized the basic 1/39.6-scale model; its purpose was to experimentally determine the types of failure modes and to give a preliminary indication of airblast and fragment patterns. It also studied the effects of model design (stiffened vs. unstiffened model) and charge shape/charge location on the observed failure patterns.

Phase II utilized a 1/6-scale model, with both scaled decks and scaled internal equipment included. The purpose of this test was to verify the previously observed failure modes and to make comparisons between the results obtained for two different scale sizes.

Phase III utilized the basic 1/39.6-scale model, with the addition of scaled internal equipment. One of the Phase III tests modelled the entire submarine, not just the region in the vicinity of the torpedo compartment. The purpose of the Phase III tests was threefold: (1) To show the effects of scaled internal equipment on the airblast and fragmentation, (2) to duplicate the 1/6-scale results, and (3) to show the effects of modelling the entire submarine. In addition to these primary purposes, these tests would also be used to study model motion and model interaction with the bottom, and to make predicitions for the full scale submarine.

Further details of the firing program for each Phase are presented in Tables 1, 2, and 3.

THE MODELS

Before the models could be constructed, certain facts and assumptions concerning the submarine and the expected phenomena had to be delineated:

(1) All internal bulkheads between the forward pressure hull and the forward wall of the reactor compartment fail immediately upon detonation. There are no water-tight compartments in this region--only curtain walls which have no resistance to blast.

(2) Only the hull in the vicinity of the torpedo compartment need be modelled accurately: the areas forward and aft of the compartment only provide expansion volume for the explosion products and quasi-static pressure. In the region of the torpedo compartment, the hull thickness must be scaled accurately.

(3) Internal stiffeners need not be modelled identically, as long as they provide the same strength to the hull. T-stiffeners are used in the real submarine and in the 1/6-scale model. In the 1/39.6-scale model, rectangular stiffeners were substituted. The dimensions of the rectangular stiffeners were chosen such that the wall/stiffener combination would fail at the same externally applied pressure as in the full scale submarine.

(4) The model is essentially a "replica" model. Pressures and velocities scale: i.e., the pressure or velocity observed in the model will be the same as in the full scale submarine; however, distances and times are scaled by the model scale factor. (This is the well-established scaling law for blast. See, for example, Baker's book on modelling[3]).

Figure 1 is a sketch of the entire submarine, showing the sections being modelled: included on this same sketch, but to a different scale, is a sketch of our basic 1/39.6-scale model. The basic model is 10-inches in diameter and 30-inches long, with the test section made from HY-80 steel. This represents the volume enclosed in the submarine from the bow to the forward wall of the reactor compartment. The test section of the model represents the volume of the submarine located between Frames 35 and 45, the region encompassing the torpedo compartment. The wall of the test section was made from HY-80 steel, formed into two hemi-cylinders 1/2-inch thick and welded together. The wall thickness of the test section was then machined down to the proper thickness (approximately 0.040 inches). The internal stiffeners were machined into the wall during this same fabrication process. The test section was then welded to the forward and aft expansion sections (Note: all welds were examined by X-ray). The ends of the models were closed with 1/4-inch steel plates, secured to the forward and aft expansion sections with 32 5/16-inch bolts. A photograph of a Basic Model is shown in Figure 2.

One of the Phase III tests tried to duplicate the Phase II test in which the end closures failed. To accomplish this, every other bolt was removed from each

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[3]Baker, W. E., Westine, P. S., and Dodge, F. T., Similarity Methods in Engineering Dynamics: Theory and Practice of Scale Modeling (Rochelle Park, NJ; Hayden Book Company, Inc., 1973).

end closure of a Basic Model. In addition, the remaining bolts were notched to weaken them.

The last shot of the Phase III tests was designed to model the shape of the entire submarine. To accomplish this, sections were added fore and aft to the Basic Model. The additional forward section consisted of a wooden ogive nose. The additional aft sections consisted of another metal cylindrical section followed by a tapered wooden section. Figure 2 is a photograph of this model, also. It should be compared with the sketch of the entire submarine presented in Figure 1.

The Phase II (1/6-scale) model was a modification of a previously-tested underwater explosion shock test model supplied by the David Taylor Naval Ship Research and Development Center. The wall thickness in the forward expansion section was 0.404 inches, and 0.251 inches in the remainder of the model. The hull material for the entire model was HY-80 steel. Scaled T-stiffeners were located in both the test section and the aft expansion section. Each end of the model was closed with a 2-inch thick steel plate welded to flanges which were in turn welded to the body of the model (Note: none of the welds on the Phase II model were inspected by X-ray or any other means). Figure 3 is a photograph of this model.

The interior of each model for all three phases of testing consisted of four levels, separated by the three platforms (or decks) present in the submarine. The thickness of the decks and the spacing between the levels corresponds to the appropriate scaled dimensions in the real submarine. Figure 4 is a sketch of a cross-section through the torpedo compartment (test section) of the submarine.

For the Phase II and III tests, an attempt was made to model or represent the equipment found inside the submarine. For the Phase II tests, the equipment consisted of boxes of electronic gear, motors, pressure tanks, etc. on Levels 1-3, and on Level 4 water tanks (filled with water) and lead-acid batteries. Figure 5 is a photograph of all of the material in the Phase II model. On Phase III, the equipment was represented with electronic components (relays, capacitors, inductors, etc.), small and large nuts, pieces of Celotex, and ribbon wire on Levels 1-3. The Level 4 equipment was represented by miniature water tanks (filled with water) and small pieces of lead, representing the storage batteries. The Celotex and ribbon wire represented material not included on the Phase II model. Figure 6 is a photograph of all the material going into a Phase III model.

THE EXPLOSIVE CHARGES

A simple, centrally-initiated spherical charge was used on the first two Phase I tests. Subsequent to that, a distributed charge was used for all remaining tests.

For the Phase I and III tests, the charges were constructed from strips of DETA-SHEET, a commercial sheet explosive, one-inch wide and 7.8-inches long. Each charge consisted of two rows of explosive, separated by an air gap. The size of the explosive strips, the spacing between the strips, the spacing between the bottom of the explosive and the decking on which it rests, and the weight of explosive, were all scaled from the full scale submarine. On the Phase III tests, aluminum blocks, representing chocks, handling mechanisms, hoists, etc., were inserted at several locations between the rows of explosive to reduce jetting. Figure 7 is a photograph showing both the components of a charge and a completed charge. The nominal explosive weight for these tests was 0.3 pounds.

The Phase II charges consisted of twenty aluminum-cased pentolite cylinders, with a total explosive weight of 62 pounds. The charges were supported by an aluminum test rig representing the chocks and hoists. The spacing between the charges and the spacing between the charges and the deck were scaled to the proper dimensions. The centermost charges were detonated simultaneously, with DETA-SHEET explosive being used to insure the transfer of detonation to the remaining charges. Figure 8 is a photograph of a completed Phase II charge.

For all the tests utilizing a distributed charge, the charge was located on Level 3, near the center of the test section. Figure 9 shows a charge in place for a Phase II test and Figure 10 shows a charge for a Phase III test.

TEST GEOMETRY

In all but the first two of the Phase I tests, the model was floating or supported in water at the proper freeboard (approximately 6 to 9 feet full scale). On both the Phase II and III tests, the water beneath the bottom of the model corresponded to twenty feet of water beneath the full scale submarine.

Figure 11 shows a typical test set up for a Phase I test. The test pit consisted of a metal box 4-feet wide, 12-feet long, and 4-feet deep, buried so that the top is flush with the ground.

Figure 12 shows the test set up for Phase II. Here, a test pit 10-feet wide, 20-feet long, and 8-feet deep was dug in the ground and lined with plastic. As can be seen in this figure, the model practically fills the entire test pit. An L-shaped extension was dug off the side of the test pit. In this region, underwater pressure-time traces were recorded.

The test pit arrangement for the Phase III tests was further refined. A metal box 10-feet wide, 30-feet long, and 2-feet deep was buried flush with the surface. This box had windows along all four sides to facilitate underwater motion picture photography. Eight inches of sand were placed in the bottom of the box, covered with a reflective cloth, and the box filled with water. Figure 13 shows the test pit for a Phase III test. Note in this figure, the lights and cameras for the underwater photography and one line of airblast transducers.

RESULTS--PHASE I

The early Phase I tests were to determine the failure mode; i.e., does it break like a pressure vessel into a few large pieces or does it fragment like a bomb case into many small pieces? The tests indicated that, indeed, the failure was similar to pressure vessel failure--a relatively few large pieces. Failure appears to occur typically by what we are now calling the "break & tear" mode -- suggested by analysis, in which a small hole is formed by some means, either by fragment impact or by some local material failure, with a crack or tear propagating outward from this point of failure. This is similar to the way a paper bag fails. Figure 14 shows this failure mode.

The later Phase I tests included scaled decks, but no scaled internal equipment. On all of these tests, the model broke into two main pieces, with the break occurring at the location of the charge. On these tests, the model pieces/debris/fragments were observed to have velocities between 30 and 75 feet per second and pieces were found as far away as 150 feet. Figure 15 is a plot of the debris pattern observed after one such shot.

Airblast was also measured on one of these tests; it was measured along three directions from the model. The results are plotted in Figure 16; worth noting is the fact that 1 psi occurs at just beyond 9 feet (for this scale)--corresponding to 350 feet, full scale.

RESULTS--PHASE II

The Phase II model did not behave totally as expected. It blew out near the charge and began to tear, and, it also violently ruptured on top. Moreover, both end closures failed and were blown off.

Debris and fragments venting out the hole in the top were observed to have velocities of up to 1000 feet per second. Fragments and debris were collected out to ranges of 510 feet. A debris map for this shot is shown in Figure 17.

The airblast measured on this shot was higher than that observed on the Phase I tests--with 1 psi occurring at a full scale range of approximately 600 feet.

Underwater pressures were also recorded on this shot. The pressure-time waveforms are presented in Figure 18. As can be seen, the waves are non-classical, exhibiting multiple peaks with relatively long durations. One measure of the mechanical shock severity of near-miss underwater explosions of conventional charges is Shock Factor. This technique assumes a classical underwater shockwave. The concept has recently been extended to non-classical wave-forms by considering an "Equivalent Shock Factor" which is based upon a combination of the underwater shockwave pressure, impulse, and energy flux density. Equivalent Shock Factors have been calculated for the waveforms in Figure 18; they range from 0.48 to 0.62 at full scale distances corresponding to 24 feet from the hull of the submarine.

RESULTS--PHASE III

One of the major purposes of the Phase III tests was to show the effect of scaled internal equipment on the observed airblast and fragmentation. Figure 19 is a plot of the airblast recorded on Test 1. As can be seen, by simply including the scaled internal equipment, the observed airblast pressures are reduced by a factor of at least 2.7. Fragment velocities between 40 and 70 feet per second were observed for all fragments and debris. Figure 20 is a debris map obtained after this shot.

On Phase III, Test 2, the end closures were designed to fail and did so. The airblast was, indeed, higher than on Test 1, but still lower than that observed on Phase II. Figure 21 is a plot showing the airblast comparison. Fragment and debris velocities were of the same magnitude as observed on Test 1--40 to 70 feet per second. Figure 22 is a debris map obtained for this shot.

On Test 3, modelling the entire submarine, the airblast pressures were the lowest recorded on any of the tests. The data are shown in Figure 23. The reason that these pressures are still lower is the added "inertial confinement" produced by the mass of the remainder of the submarine. Debris velocities were again the same as observed on Tests 1 and 2. Figure 24 is a plot of the observed debris.

Model motion was observed both in the water and in the air for the Phase III tests. On test 3, we observed the two pieces of the model to be moving apart at a velocity of 60 feet per second. Figure 25 is a sketch of the early-time model motion observed on all Phase III tests. This sketch is derived from underwater high-speed photography taken by the Denver Research Institute.

DISCUSSION

We are now certain that the observed Phase II airblast and fragmentation results are not typical of a submarine, but are attributable to artifacts of the model construction. The end closures blew off--an occurrence not happening on Phase I and III (except as planned). On the Phase II test, the end closures were welded instead of being bolted, and the quality of the welds was probably not good enough. The catastrophic failure and venting out the top of the model can be largely attributed to the way the "crews quarters" were modelled on the second platform. Instead of representing the low density bedding material with something like cork or Celotex, air was substituted; i. e., the spaces were left open. This density difference led to a phenomena called "channelling", first described by Porzel in 1958.[4] In essence, the blast is drawn or channelled into areas of lower density--providing a preferred path for the shockwave and gasses. This path, aimed directly at the roof, caused the top to fail. When it did, the escaping gasses accelerated debris and fragments to the observed velocities of 1000 feet per second.

Test 2 of Phase III was supposed to duplicate the Phase II results. Indeed, the end plates failed as planned. However, the top did not blow out. This was because on this test, the crews quarters were more accurately modelled, thus not establishing a preferred shockwave path. Since no venting out the top occurred, the airblast was not as high as the Phase II levels. Moreover, the high fragment velocities observed on the Phase II test were not seen on this test.

The Phase III tests were the most accurate models. On both these and the Phase I tests, an "upper limit" fragment velocity of 75 feet per second was observed. A velocity of 75 feet per second corresponds to a vacuum range of under 200 feet. This agrees well with the observed Phase I and III fragment ranges of up to 150 feet.

The Phase III tests and analyses indicate that we can account for the 1/6-scale behavior. If this is true, then full scale results, based on 1/39.6-scale data, should also be valid. If anything, full scale results based on 1/39.6-scale data should be conservative for several reasons. Among these are:

(1) Less Equipment/Debris than for the real submarine. It was not possible to cram our model as full of equipment as is on the real submarine. It has been said that on a nuclear submarine, there is not one cubic foot of space that is not devoted to or assigned to some function.

(2) Continuous charge versus discrete warheads. The fact that a continuous charge was used simulates mass detonation of all the warheads in the full scale submarine. Recent analytic evidence raises

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[4]Porzel, F. B., "Some Hydrodynamic Problems in Reactor Containment," Second United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1958.

questions as to whether or not all of the warheads located within the torpedo compartment will mass detonate.

(3) Model construction--poorer welds and fabrication techniques. It is much more difficult to fabricate and machine models in sub-scale than to work with the full-sized submarine. The stiffeners machined into the 1/39.6-scale models had "sharp corners" inviting stress concentrations, which lead to break & tear modes of failure. These would not be present in the full scale submarine.

(4) Less time for dissipation--full scale is a better energy absorber. Since time scales by the model scale factor, there is less time for dissipation in the 1/39.6-scale; i. e., even more energy would be absorbed by the equipment/debris on the full scale submarine.

CONCLUSIONS

The Phase III tests represent our most accurate modelling, and thus, should be used to determine a safe handling arc for this type of submarine.

Based on all the airblast observed on the Phase III tests, and scaling it up to full scale ranges, 1 psi occurs within 200 feet of the submarine.

Since we observe fragment/debris velocities of only 75 feet per second (or less), this means no fragments having these velocities can go beyond a range of 200 feet.

Thus an acceptable safe handling arc around nuclear attack submarines is 200 feet.

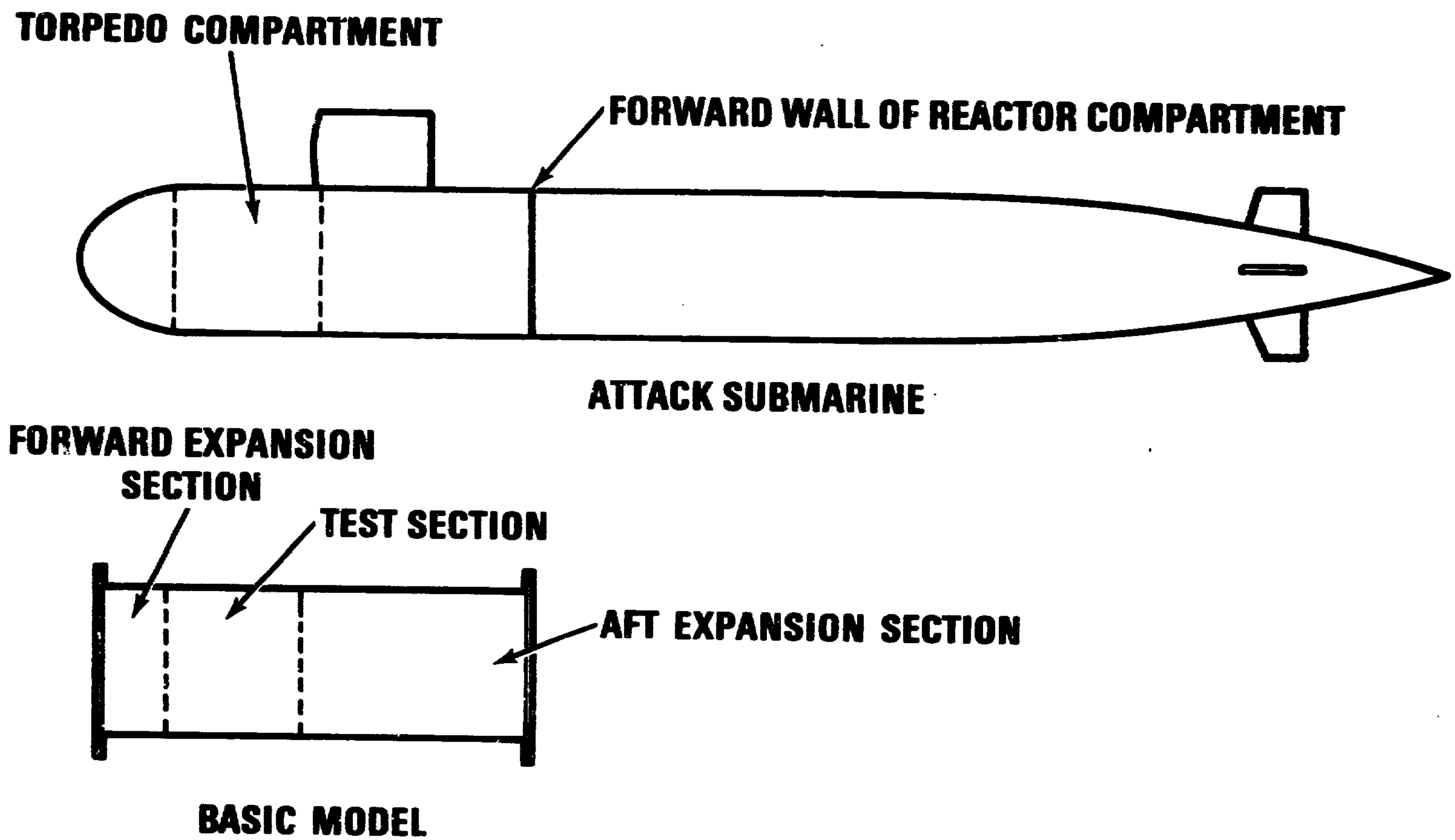
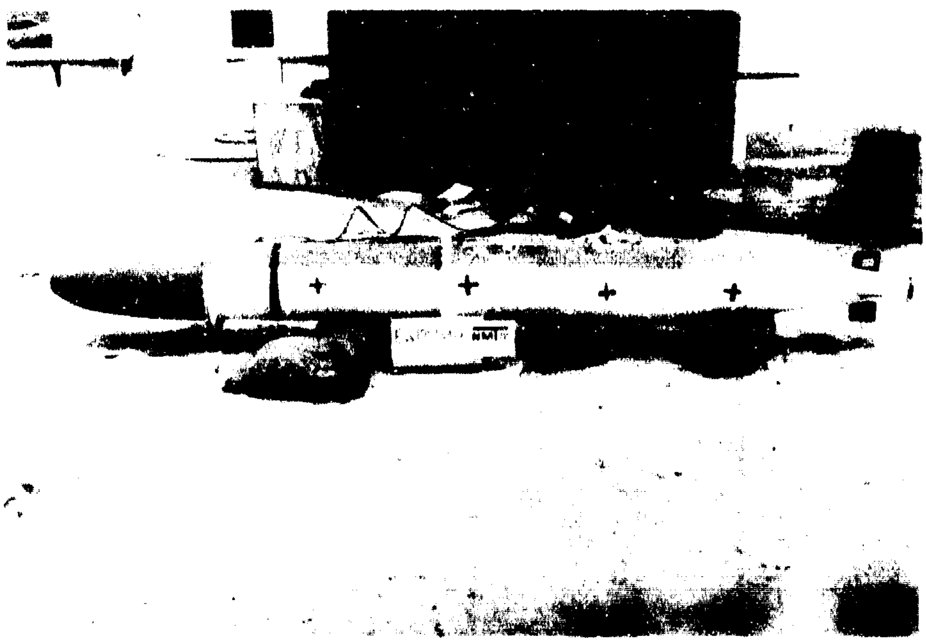


FIGURE 1. ATTACK SUBMARINE VERSUS BASIC MODEL

PHASE I



PHASE III

FIGURE 2. BASIC MODEL AND PHASE III-3 MODEL

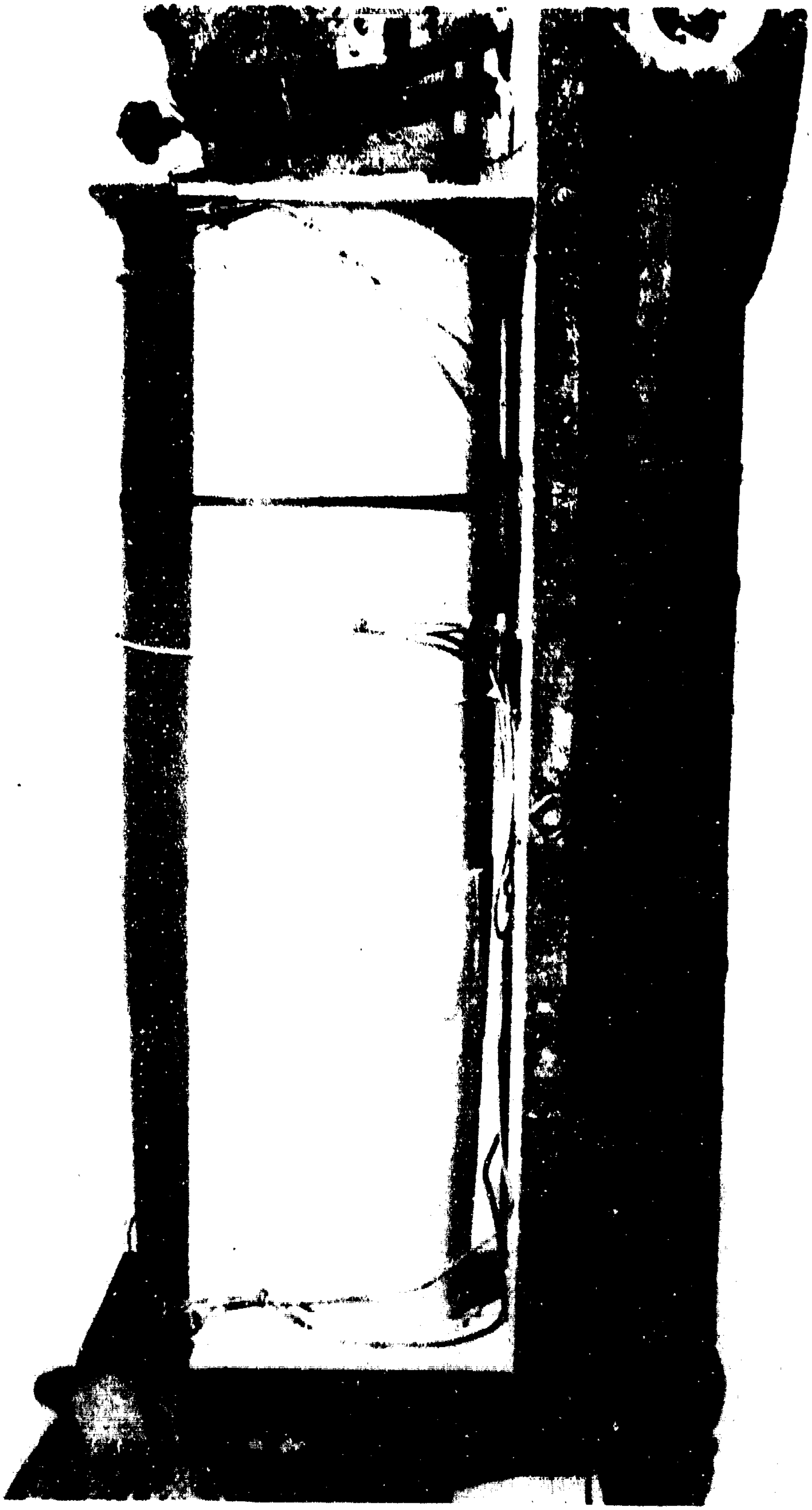
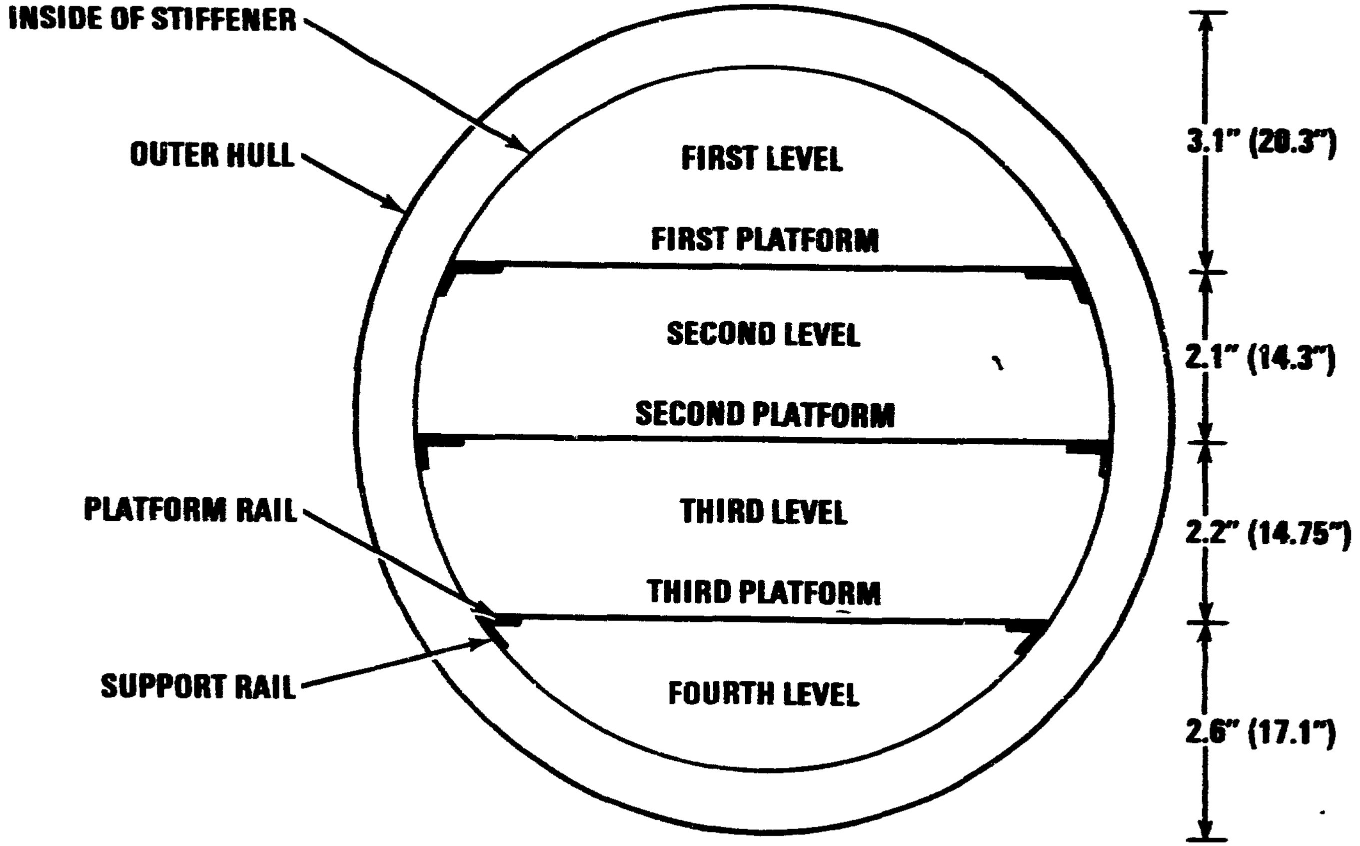
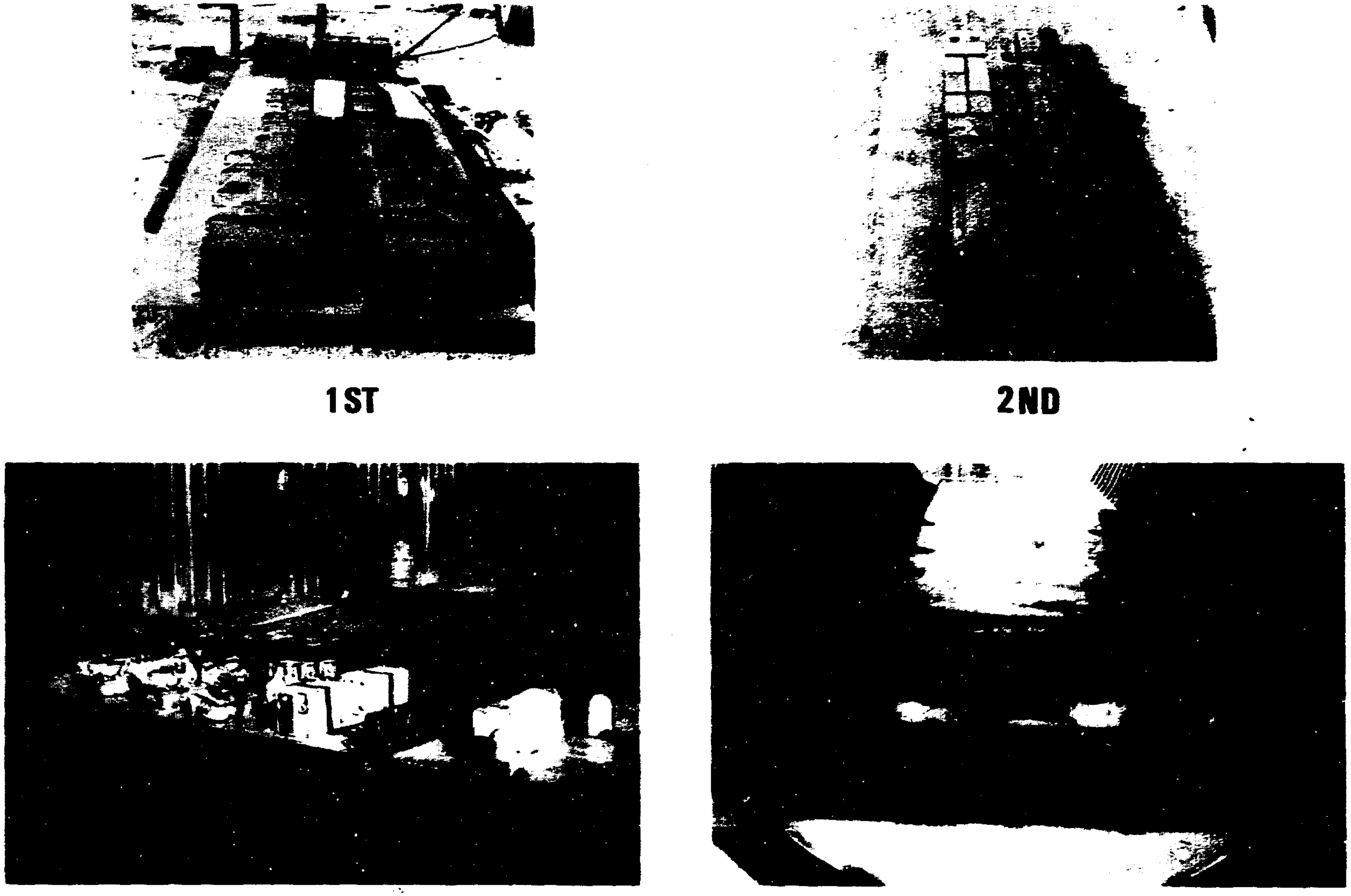


FIGURE 3. PHASE II MODEL



NOTE: SPACING SHOWN FOR PLATFORMS ARE MEASURED FROM THE INSIDE OF THE HULL—NOT FROM THE STIFFENERS. NUMBERS IN PARENTHESES REFER TO PHASE II MODEL

FIGURE 4. MODEL CROSS SECTION



1ST

2ND

3RD

4TH

FIGURE 5. ALL MATERIAL GOING INTO PHASE II MODEL

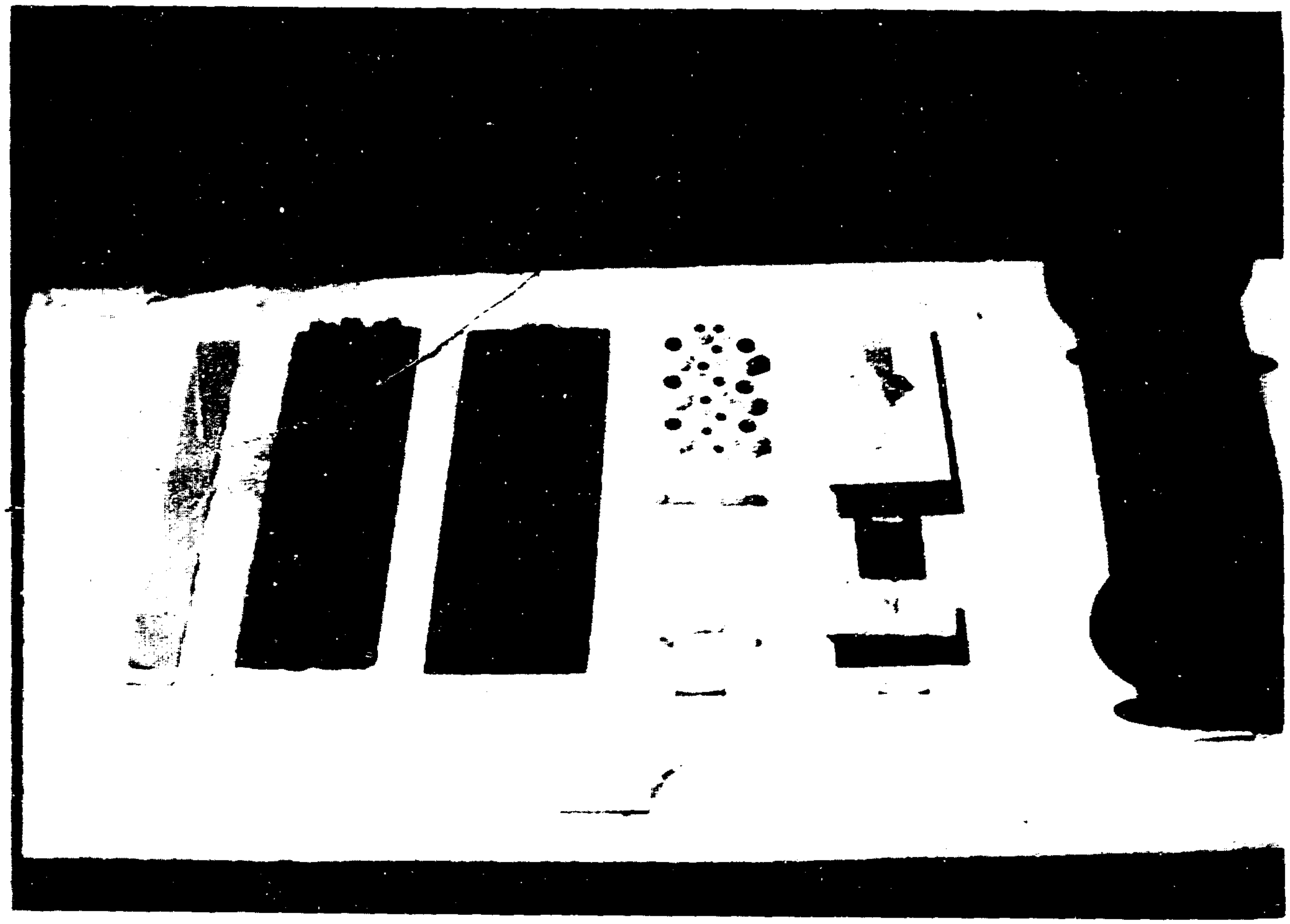
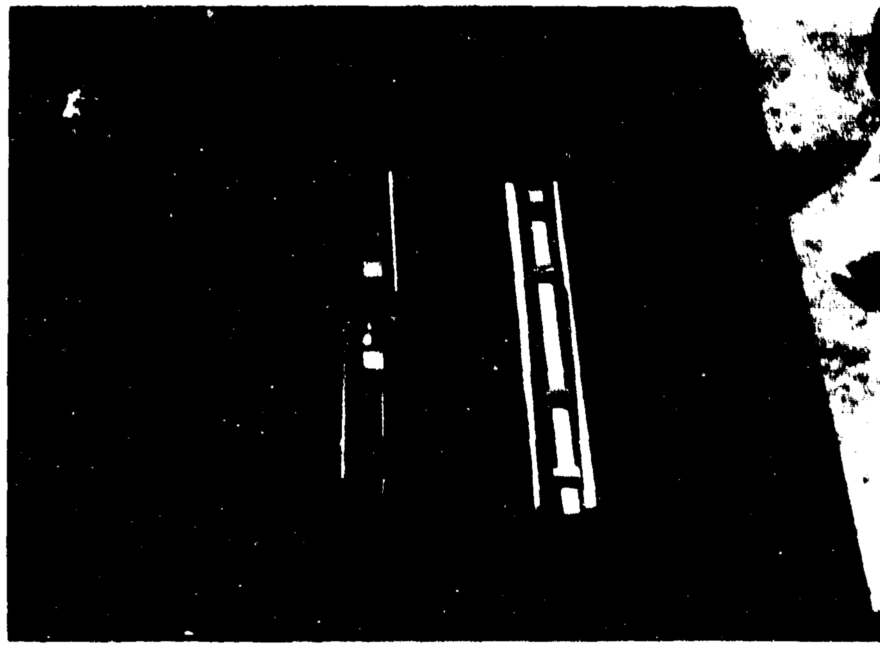


FIGURE 6. ALL MATERIAL GOING INTO A TYPICAL MODEL



CHARGE COMPONENTS

COMPLETED CHARGE

FIGURE 7. PHASE I & III CHARGE

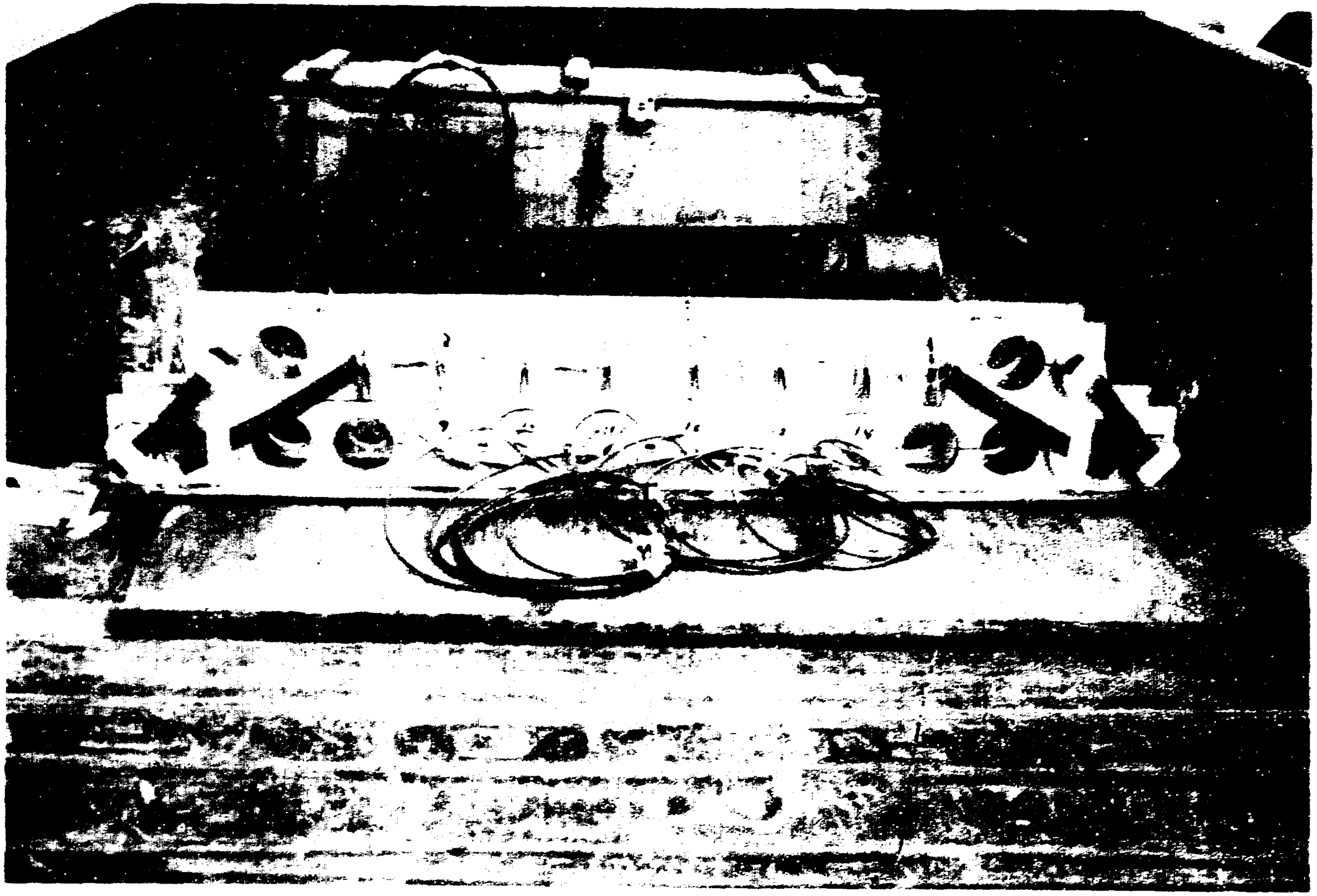


FIGURE 8. PHASE II CHARGE

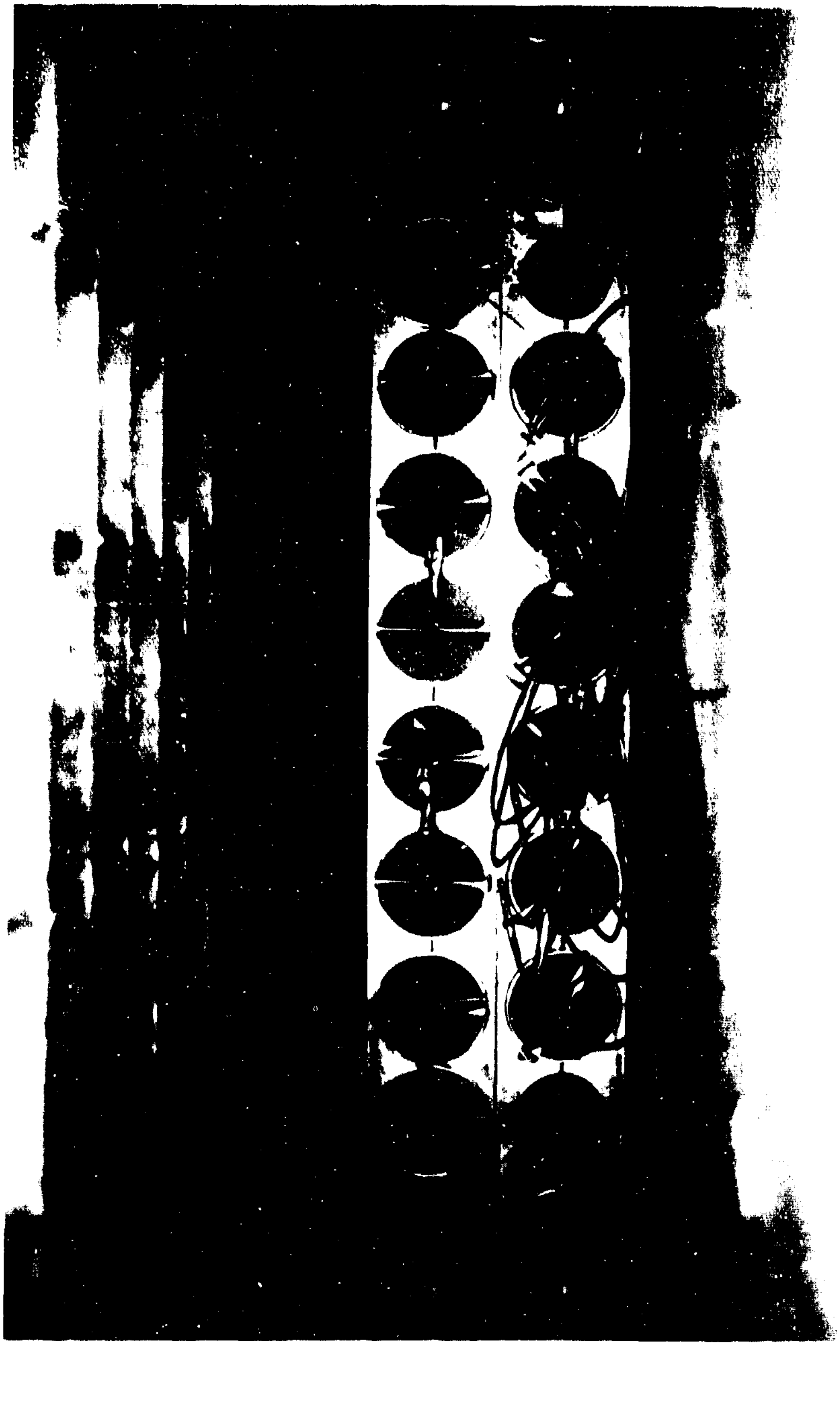
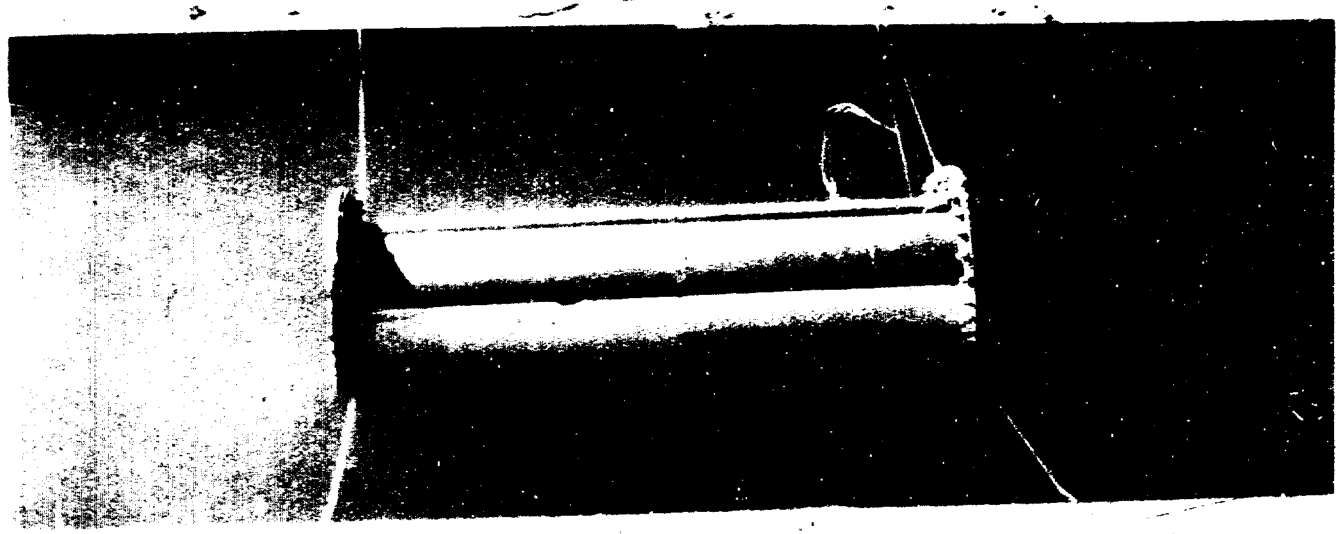


FIGURE 9. DISTRIBUTED CHARGE IN PLACE ON THIRD PLATFORM (PHASE II)

FIGURE 10. CHARGE IN PLACE ON THIRD PLATFORM OF MODEL (PHASE III)



EW0711A9

FIGURE 11. TEST SET-UP PHASE I

FIGURE 12. TEST SET-UP PHASE II

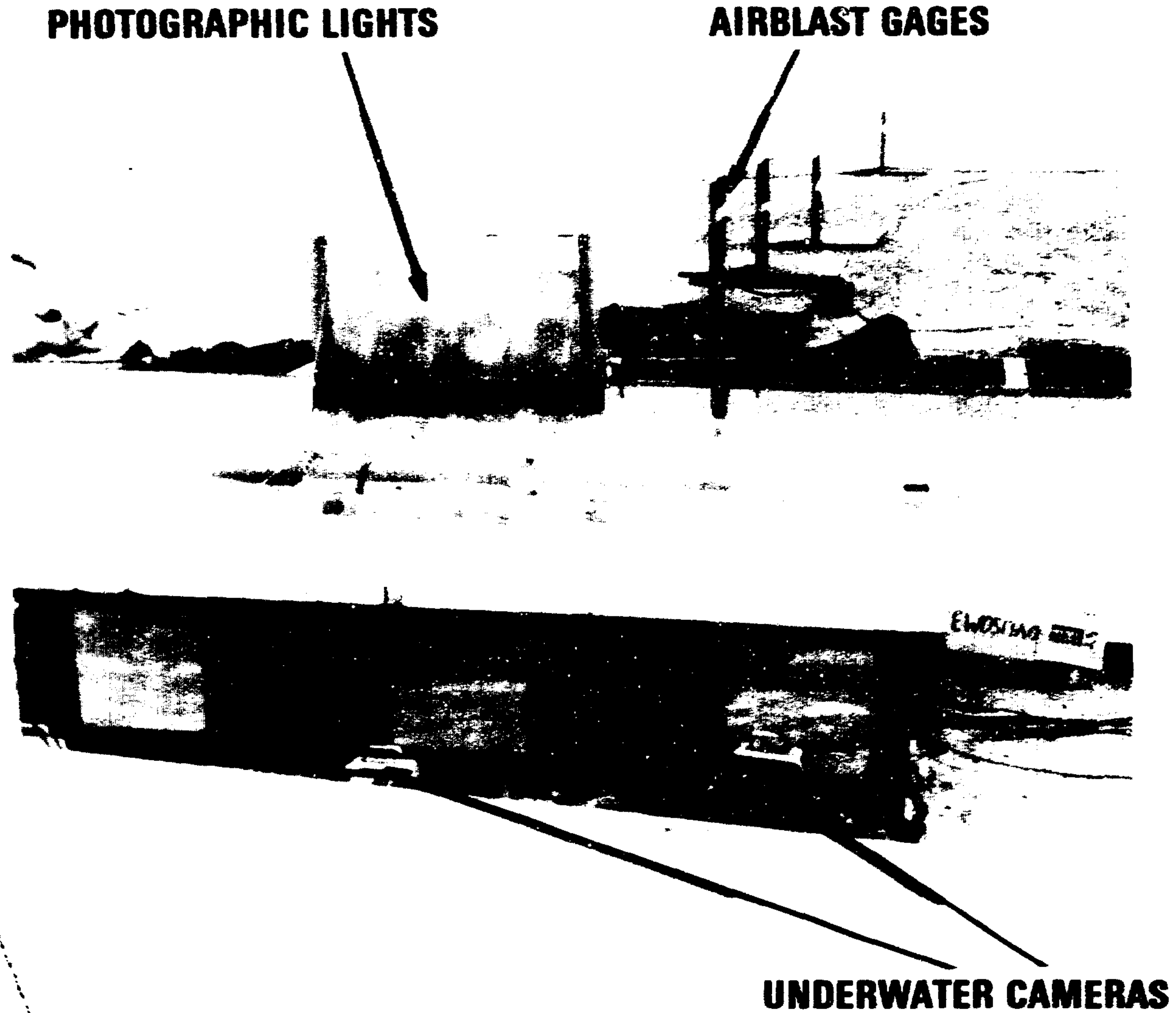


FIGURE 13. TEST PIT WITH FLOATING MODEL — PHASE III

FIGURE 14. MODEL FAILURE — BREAK AND TEAR MODE

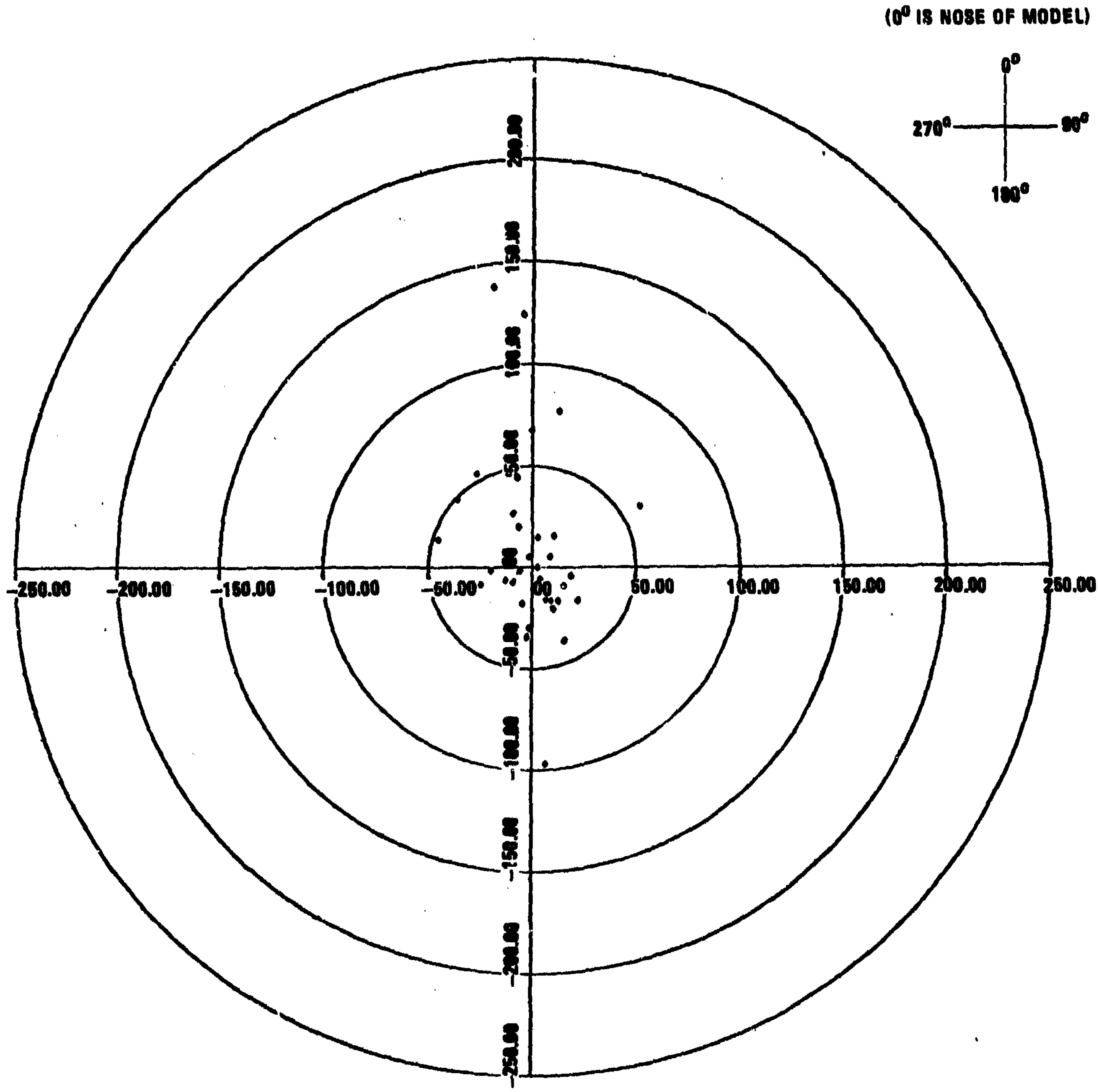


FIGURE 15. 1/39.6-SCALE MODEL (HULL, DECKING & STIFFENERS) (34 PIECES)

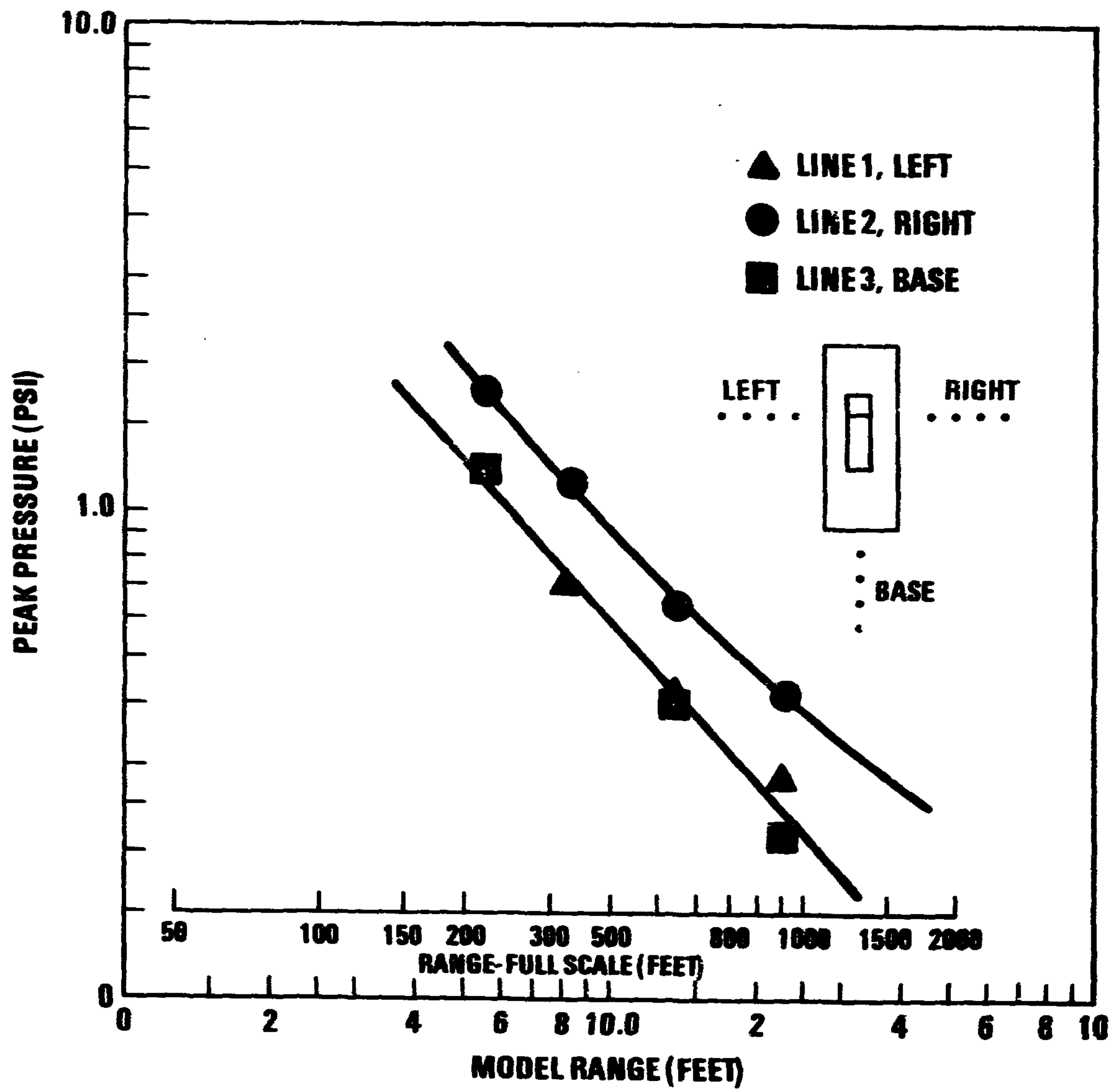


FIGURE 16. PHASE I AIRBLAST RESULTS

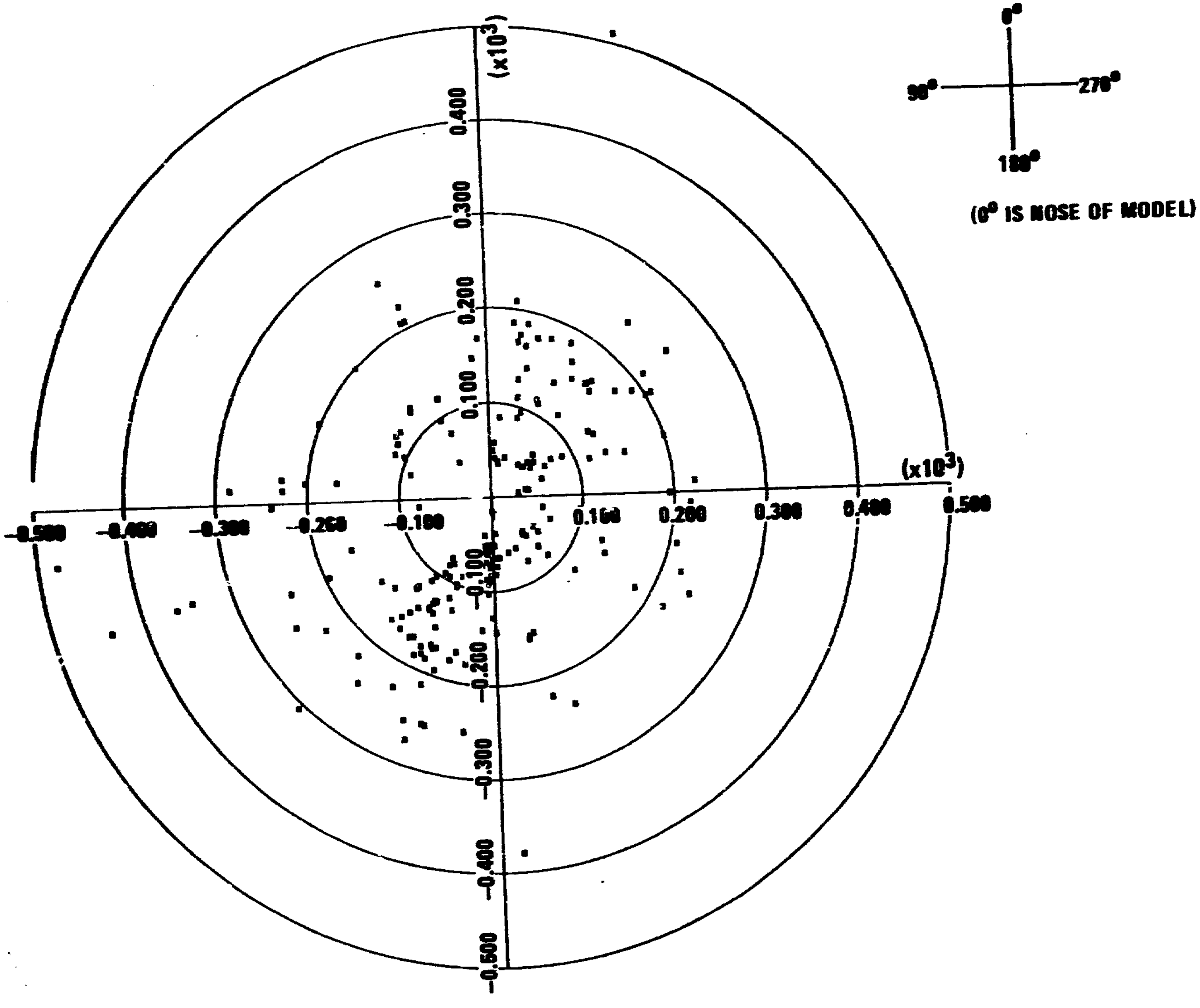


FIGURE 17. FRAGMENT RECOVERY MAP--
1/6-SCALE MODEL (ALL FRAGMENTS)

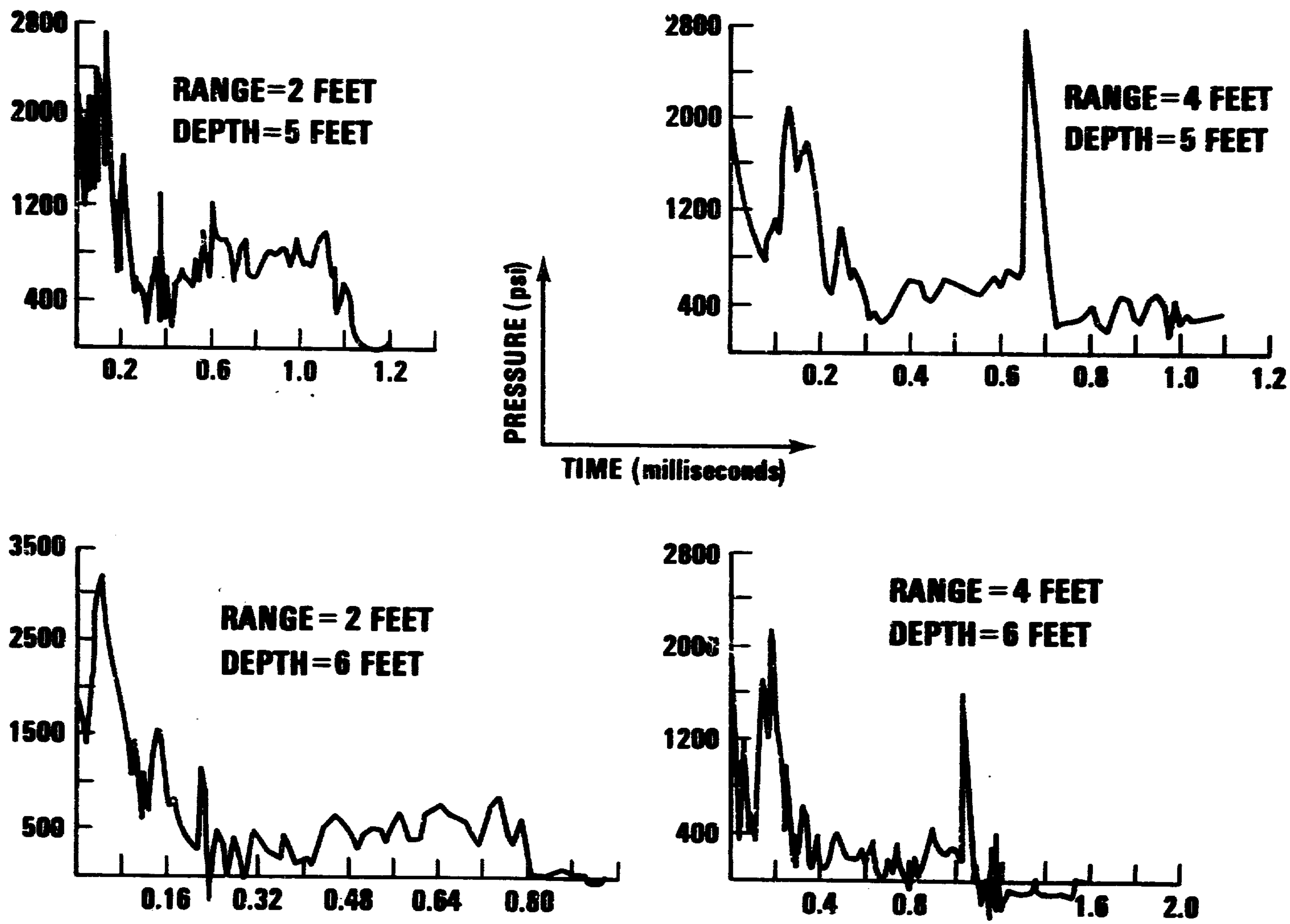


FIGURE 18. UNDERWATER PRESSURE-TIME WAVEFORMS--PHASE II

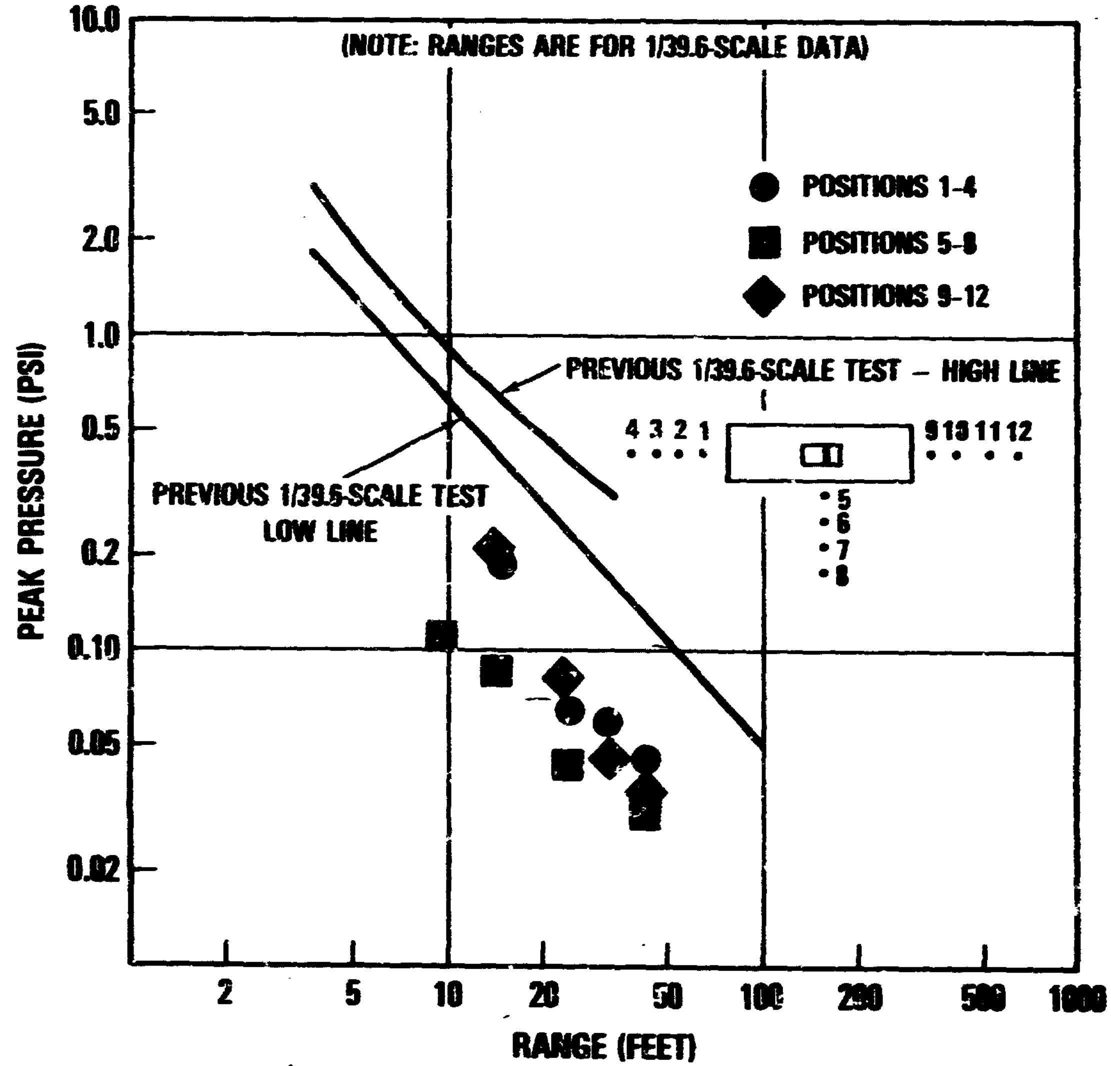


FIGURE 19. PHASE III TEST 1 AIRBLAST RESULTS

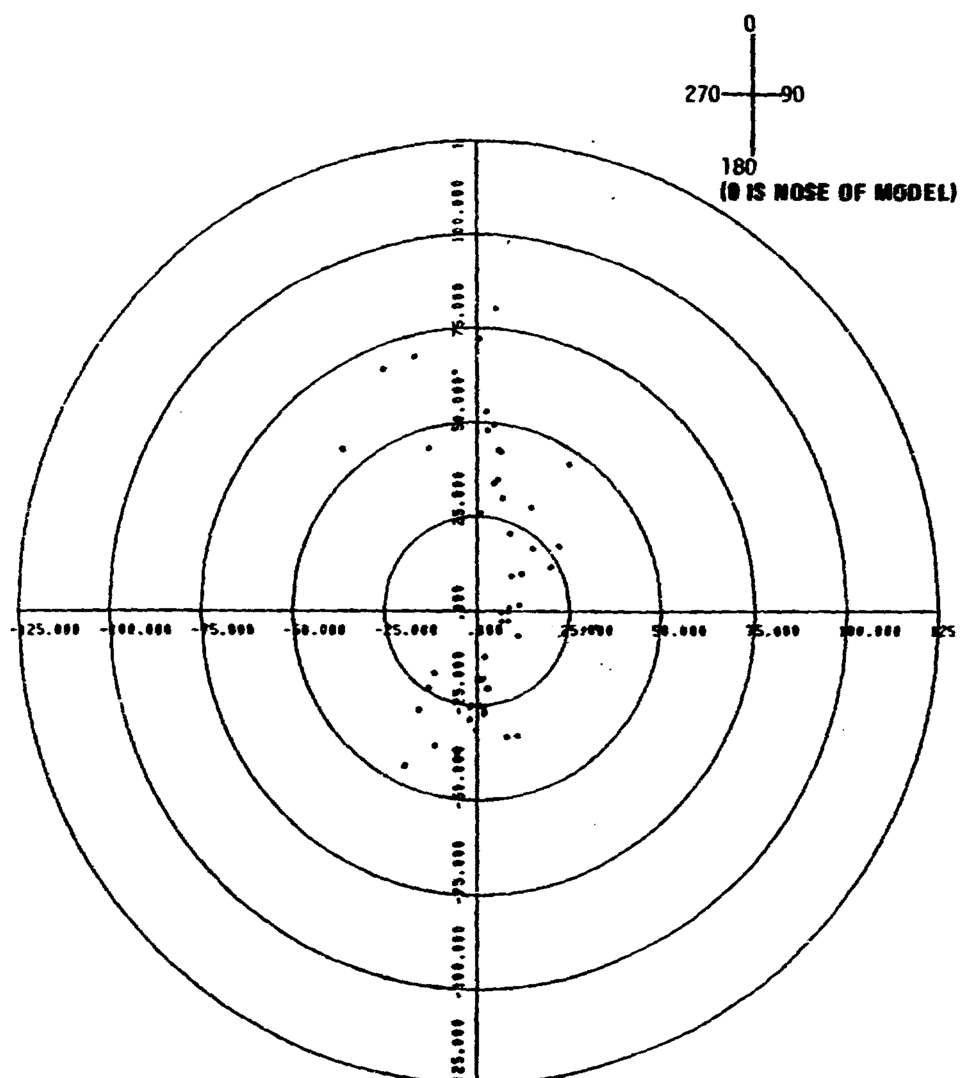


FIGURE 20. POST-SHOT DEBRIS MAP OF PHASE III TEST 1

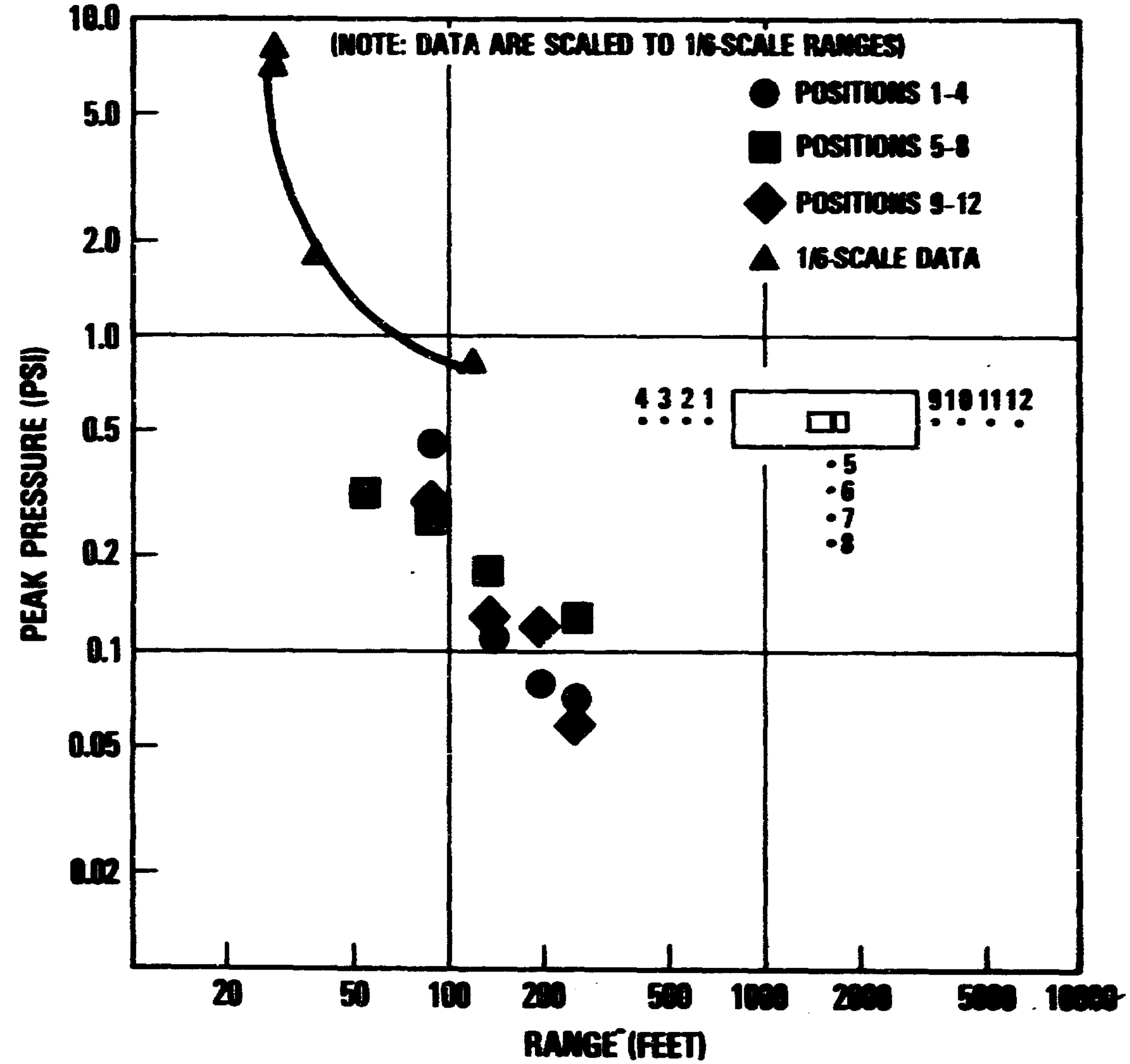


FIGURE 21. PHASE III TEST 2 AIRBLAST RESULTS

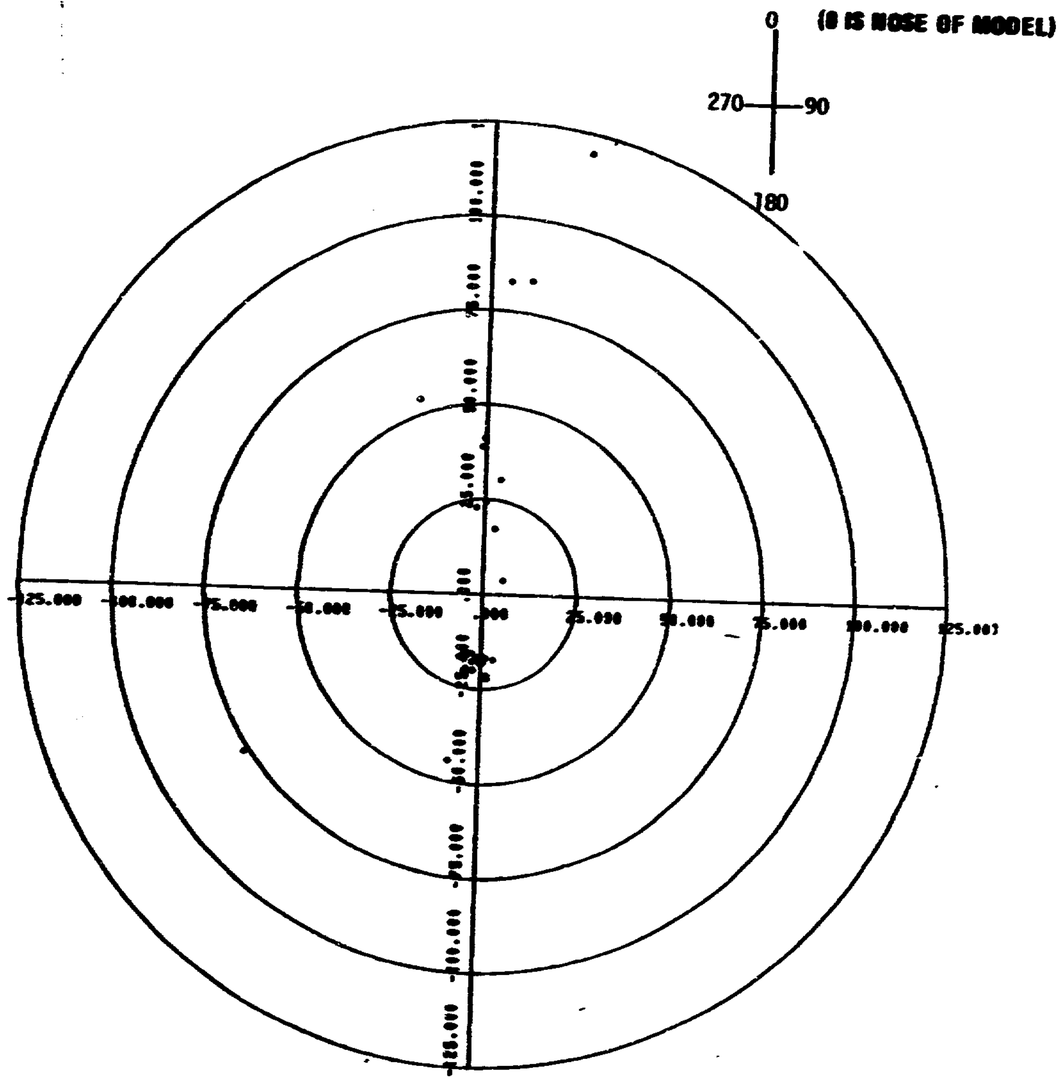


FIGURE 22. POST SHOT DEBRIS MAP OF PHASE III TEST 2

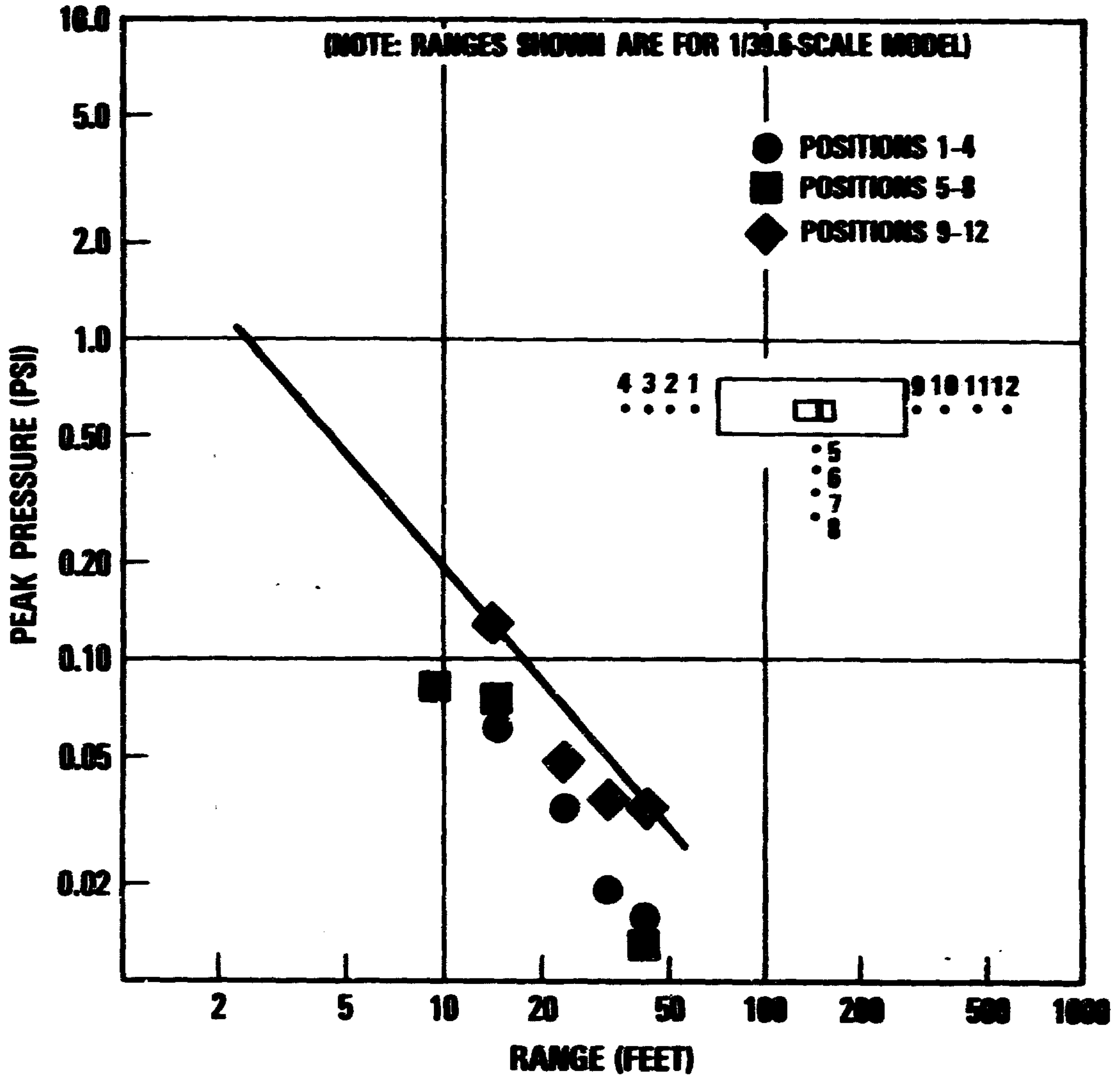


FIGURE 23. PHASE III TEST 3 AIRBLAST RESULTS
(FULL SUBMARINE MODEL)

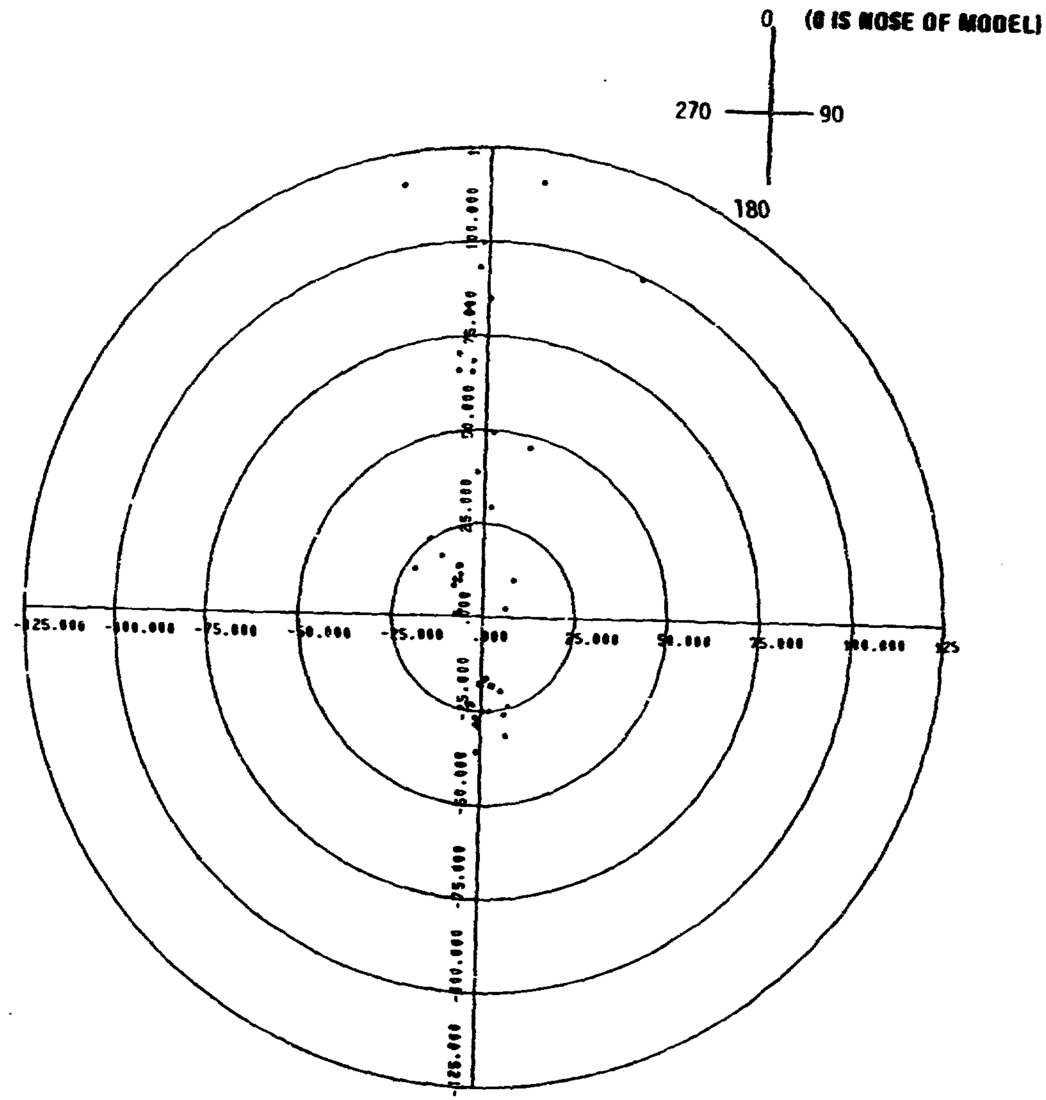


FIGURE 24. POST SHOT DEBRIS MAP OF PHASE III TEST 3

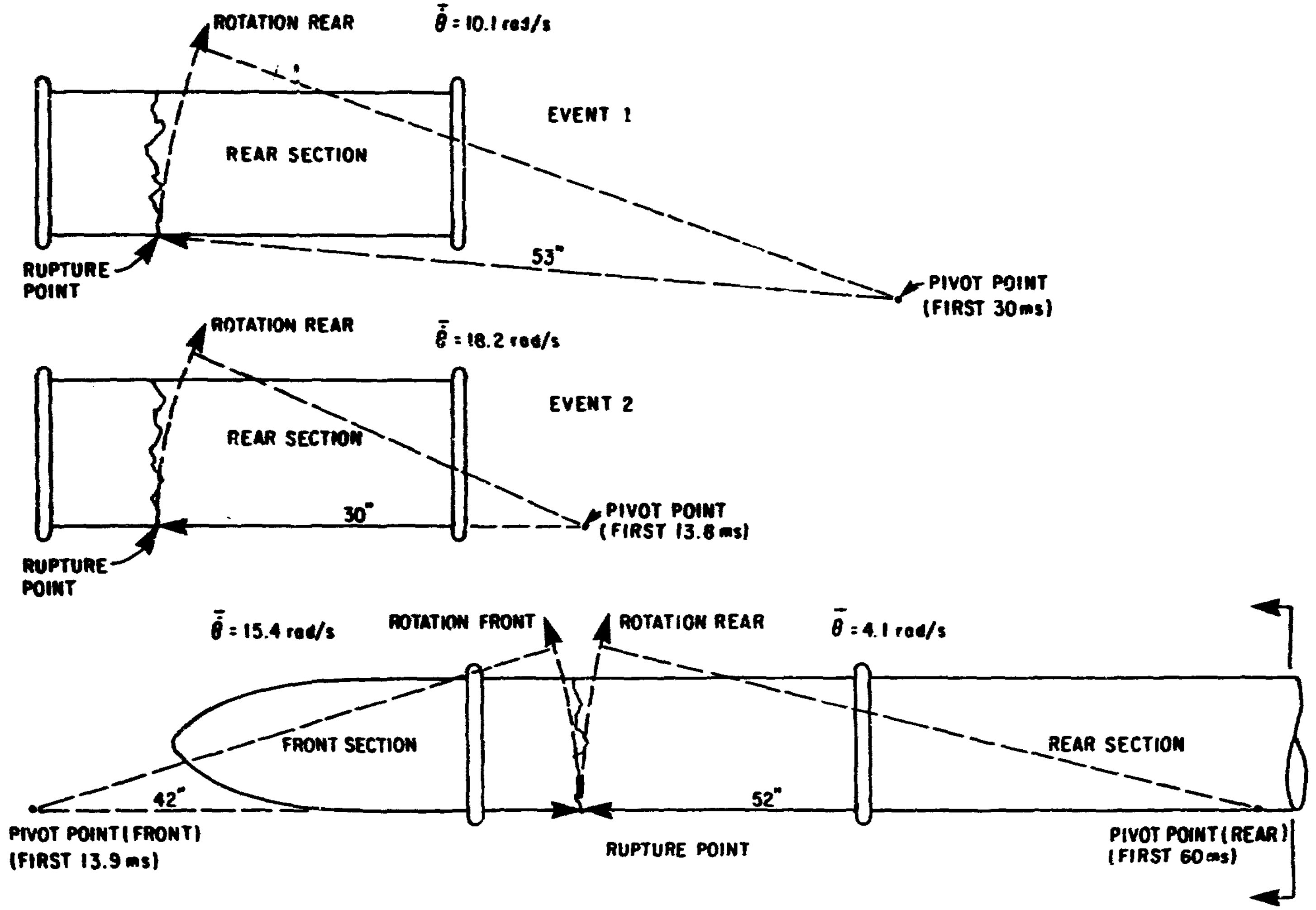


FIGURE 25. PIVOT POINTS AND RADII FOR PHASE III TESTS

TABLE 1
PHASE I MODEL TESTS (1/39.6-SCALE)
(APRIL-AUGUST 1979)

TEST 1	UNSTIFFENED TEST SECTION SPHERICAL CHARGE★ CHARGE CENTRALLY LOCATED MODEL IN AIR TEST PURPOSE--DETERMINE FAILURE MODE
TEST 2	INTERNALLY STIFFENED TEST SECTION SPHERICAL CHARGE★ CHARGE CENTRALLY LOCATED MODEL IN AIR TEST PURPOSE--DETERMINE FAILURE MODE
TEST 3	INTERNALLY STIFFENED TEST SECTION THREE DECKS PRESENT DISTRIBUTED CHARGE★ CHARGE LOCATED ON THIRD DECK MODEL AFLOAT IN WATER WITH PROPER FREEBOARD TEST PURPOSE--DETERMINE FAILURE MODE
TEST 4	SAME MODEL AND CONDITIONS AS TEST III TEST PURPOSE--MEASURE AIRBLAST AND FRAGMENTATION AND TO VERIFY FAILURE MODE OBSERVED ON PREVIOUS TEST
TEST 5	SAME MODEL CONDITIONS AS TEST III TEST PURPOSE--OBSERVE EARLY-TIME MOTION AND TO VERIFY FAILURE MODE OBSERVED ON PREVIOUS TESTS

★ SIMULATING VICTOR LOAD

TABLE 2
PHASE II MODEL TEST (1/6-SCALE)
(NOVEMBER 1979)

INTERNALLY STIFFENED MODEL

THREE DECKS PRESENT

SCALED INTERNAL EQUIPMENT PRESENT

SCALED INDIVIDUAL WARHEADS, SIMULTANEOUSLY DETONATED ★

MODEL AFLOAT IN WATER WITH PROPER FREEBOARD

TEST PURPOSE——VERIFY SCALING

★ UNIFORM LOAD SIMULATED

TABLE 3
PHASE III MODEL TESTS (1/39.6-SCALE)
(MAY 1980)

TEST 1	INTERNALLY STIFFENED TEST SECTION 3 DECKS PRESENT SCALED INTERNAL EQUIPMENT DISTRIBUTED CHARGE* MODEL AFLOAT WITH PROPER FREEBOARD TEST PURPOSE – TEST STANDARD MODEL WITH SIMULATED INTERNAL EQUIPMENT
TEST 2	SAME AS TEST I, BUT WITH WEAKENED END CLOSURES TEST PURPOSE – TO REPRODUCE 1/6-SCALE RESULTS
TEST 3	BASIC TEST I MODEL WITH ADDITIONS OF SIMULATED FORE AND AFT SECTIONS OF SUBMARINE TEST PURPOSE – TEST EFFECT OF MODELLING FULL SUBMARINE ON RESULTS

* UNIFORM LOAD SIMULATED

DLA SAFETY CERTIFICATION PROGRAM

Carla J. Doggett
Defense Contracts Administration Region
Los Angeles, California

Around 1971, the Defense Logistics Agency (DLA) Safety Certification Program was established to assure personnel were well qualified in explosives and industrial safety, to perform the important and unique Specialized Safety functions.

At the start of the Certification Program, each safety engineer, manager, and specialist who occupied a position within the Directorate of Quality Assurance at the DLA HQ, DCASR, and District levels was required to be certified. The Certification Program also would require newly hired safety engineers, managers, and specialists to become certified before they could perform the technical functions of their jobs. Military were exempt from the certification requirements.

Back then, the requirements for certification were very limited. All one had to do was attend the DARCOM munitions safety course and certification would soon follow. Since then the program has grown by leaps and bounds. Today's certification program is divided into two areas: explosives safety and industrial safety. Certification in both areas is the primary objective. Before certification is granted, however, the person must qualify by meeting the experience and training requirements. There are three ways to qualify for each certification area:

1. The qualifications for industrial safety certification are:

   a. Completion of all prescribed or equivalent courses for industrial safety certification (see matrix), and one year experience in the field of industrial safety.

   or

   b. Completion of 50% of prescribed or equivalent courses for industrial safety certification, and three years experience in the field of industrial safety.

   or

   c. Completion of 50% of prescribed or equivalent courses for industrial safety certification, and one year of satisfactory hands-on experience at explosives and nonexplosives facilities accompanied by a certified safety specialist/manager.

2. The qualifications for explosives safety certification are:

a. Completion of all prescribed or equivalent courses for explosives safety certification (see matrix), and one year experience in the field of explosives safety.

or

b. Completion of 50% of prescribed or equivalent courses for explosives safety certification, and accompany a certified specialist/manager on three consecutive safety surveys at each explosives facility for which the uncertified specialist/manager will be responsible.

Once the qualifications are met, which can take anywhere from 3 months to 2 years, certification is requested from DLA HQ. When DLA HQ awards certification, a letter and card are provide as proof of certification. Safety trainees are certified upon graduation from the training program.

Certification, however, does not end with a letter and card. Certification is required to be renewed on a continuing basis. To remain current in explosives safety, explosives safety training must be obtained every two years from any one of the following sources: (1) an accredited course, (2) cross training at any Army ammunition plant (AAP), or (3) the DoD Explosives Safety Seminar. To remain current in industrial safety, attendance is required at one of the industrial safety-type courses listed on the matrix, or its equivalent, every three years.

The Certification Program is essential to the Specialized Safety mission. Every safety specialist/manager/engineer must attain certification in explosives and industrial safety to perform duties of the Specialized Safety function. The program requires training and experience for both areas to be certified. Once certification is achieved, it must be kept current through training.

DLA SAFETY CERTIFICATION PROGRAM

CERTIFICATION COURSE REQUIREMENTS MATRIX

Industrial Safety

Applied Hazards & Human
Reliability Analysis
NAVSEA Safety School

*Electrical & Electronics Safety
NAVSEA Safety School

*Public Safety Law
NAVSEA Safety School

*Occupational Safety
DARCOM FSA

*Safety Management
DARCOM FSA

*Fire Hazard Control
NAVSEA Safety School

*Safety in Chemicals Operations
National Safety Council

Systems Safety Analysis
NAVSEA Safety School

Laser Safety
DARCOM FSA

Ionizing Radiation Safety
NAVSEA Safety School

Nonionizing Radiation Safety
NAVSEA Safety School

Laboratory Safety
National Safety Council

Explosives Safety

*Munitions Safety
DARCOM FSA

*Basics of Explosives
Hazard Control
NAVSEA Safety School

Applied Hazards & Human
Reliability Analysis
NAVSEA Safety School

Cross Training at an AAP

*Electrical & Electronics
Safety
NAVSEA Safety School

*Public Safety Law
NAVSEA Safety School

Occupational Safety
DARCOM FSA

Safety Management
DARCOM FSA

DDESB Seminar

*Course or its equivalent is mandatory for certification area.

PRE-AWARD SAFETY SURVEYS

PETER TUTTLE

The pre-award survey, when employed properly, is a tool to aid the contracting officer in determining the responsibility of a prospective contractor. "Responsibility" is an admittedly vague concept; however, Defense Acquisition Regulation (DAR) Section I, Part 9, enumerates specific criteria to be used to define responsibility. Essentially, the contractor must have the financial and physical resources necessary to deliver the product within the specified delivery time. This seems self-evident, but is the duty of the contracting officer to insure, according to Section 1-902 of the above mentioned DAR, the "...purchases shall be made from, and contracts awarded to, responsible contractors only." Hence the pre-award survey. The contracting officer requests a pre-award survey on DD Form 1524, Pre-Award Survey of Offeror-General, to the applicable contract administration function. At this point, the Defense Contract Administration Services (DCAS) enters the picture. DCAS is frequently called upon to perform pre-award surveys at prospective contractor facilities. When the request is received at the DCAS office, it is evaluated by the pre-award monitor. The pre-award monitor is an individual who is designated to administer the survey from request to the final report. The monitor's duties are addressed in Appendix K of the DAR, Section K-2302. These duties can be condensed to the non-specific phrase "riding herd." The monitor evaluates the request, and notifies specific technical representatives as needed to perform the survey. Specialized Safety is one among many technical representatives.

Part 3 of Appendix K deals with the specific survey. The three steps necessary for survey completion are spelled out briefly as follows:

1. Preliminary Analysis: This is the foundation that the pre-award monitor must lay. It is simply a review of the request to establish the basic information sought by the contracting officer.

2. Development and Evaluation of Information: This is the role of the staff specialists. They evaluate the proposed contractor's plans and systems, employing data obtained from diverse sources, including an on-site survey.

3. Preparation and Review of the Pre-Award Survey Report: Each technical specialist reports and recommends award or no award to the pre-award monitor. The monitor then makes a final decision based upon all of their reports. This decision is submitted with a summary to the review board. The review board either approves or disapproves and the pre-award monitor makes a report to the contracting officer.

Thus concludes the pre-award process, on paper. Most people within the government are all too familiar with this particular chain of events. The question becomes: Where are the weak links in this chain? Particularly in the field of explosives, it is imperative that there are none, yet problems still arise. A close look at the process just described makes the shortcomings apparent. Appendix I is a sample Form 1524. Part III, Section 9

is the block that is to be checked when a plant safety survey is desired. The obvious question to ask is: Who checks that box? If the PCO recognizes the product being procured as hazardous, there are no problems. However, many innocuous sounding procurements involve hazardous materials or explosives. A good example is a cartridge activated oxygen mask produced in the Philadelphia region. The actual amount of propellant used in the cartridge is small, and the cartridge is a relatively minor component of the overall system, yet the cartridges are loaded by the contractor on site. This involves maintaining a storage facility and employing all of the proper safeguards mandated by DoD 4145.26M, The Contractors Safety Manual. However, this manual was not referenced in the invitation for bids. (It should be mentioned here that this manual is referenced by DAR 7-104.79, Safety Precautions for Ammunition and Explosives, which is required in all contracts involving explosives.)

So, a crack exists. This one, fortunately, was caught. Unfortunately, it raises the spectre of a contractor doing work with explosives without the DCAS Safety Specialist's knowledge. On contracts where explosive devices are the primary item, the possibility of this happening is virtually nil. As already demonstrated, however, when the use of explosives is incidental to the end item, the possibility of a mistake is much greater. There is one safeguard built into the system. The PCO is not the only person who may check the plant safety box. The pre-award monitor, who is in a better position to know the specific facility to be surveyed, may also ask for Specialized Safety participation. This is typically done on a non-explosive contract when there is some reason to doubt the safety program of the bidder. As an aside, although non-explosive pre-awards are beyond the scope of this seminar, it should be pointed out that there is a gaping hole in DCAS pre-award surveys of non-explosive bidders. On explosive contracts, DoD 4145.26M provides a specific set of criteria with which to judge a bidders program, much as a Quality Assurance pre-award survey looks at the quality program. However, on non-explosive contracts, there are no specific criteria with which to evaluate a safety program. OSHA Standards, ANSI, NFPA, and others all give detailed safety standards, but are not except by somewhat tenuous logic mandated by contract. Since an evaluation to these standards is impractical at best, the industrial pre-award all too often turns into an opportunity to note deficiencies, and then a rubber stamp approval.

That digression aside, the problem that the pre-award monitor has is essentially the same one that the PCO faces; that neither is really in a position to evaluate safety concerns. Another anecdote helps illustrate. A contract waa proposed in which the bidder was to employ extremely sophisticated analytical techniques to measure DDT in a water supply to as low as 300 parts per trillion. The risks posed by such an operation are far less than those posed by the general machining of any widget, yet the plant safety box was checked. Clearly, the fact that DDT was involved triggered a reaction in someone's mind, and the safety pre-award was requested. The point of this story is that because DDT is assumed by non-safety people to be hazardous, it requires a safety pre-award, while other operations which in fact are much more hazardous than the one just described are contracted with no safety pre-award not just daily, but hourly. This dependence on non-informed people for safety decisions is the major fly in the ointment of the pre-award program.

It is easy to see this hole in the program. All DCAS Safety personnel have probably run across it more than once. What is not so easy to see is a solution. This seems to be a case where the system is recognized as being imperfect, but the only practical way of doing business. The sheer volume of pre-award requests handled by DCAS makes it impossible for the Safety Specialist to evaluate them all; in fact, a random (and admittedly not very rigorous) sample revealed that Safety participated in only about 10% of the pre-awards that the Quality Assurance Directorate received. (It should be noted that within DCAS, Specialized Safety is a division of the Quality Assurance Directorate). A greater safety awareness by both the PCO and the pre-award monitor would help, but they certainly don't have the time to become Safety Specialists. Perhaps the best solution is to go all the way back to the requesting activity. They certainly know the product better than anyone else, and a Safety Specialist there, if consulted, would be able to determine quite easily if safety was a major consideration. Of course the procurement procedure for different activities varies considerably; some, like Picatinny Arsenal from personal knowledge, have excellent safety participation in procurement, while at other facilities, the safety office serves an accident prevention function and is not integrated into the procurement process. This is a problem for a Safety Management Seminar, and is obviously far afield from a discussion of pre-award surveys, but actually is the only real area where the types of problems encountered in the pre-award system can be addressed.

This paper is intended to sound alarmist; please bear in mind that the actual possibility of an explosives contractor slipping through the pre-award net is quite small. However, as mentioned earlier, the potential does exist, and the thought of a major accident at a plant that was somehow overlooked is sobering enough to warrant the constant vigilance of everyone within the procurement process. Such mistakes must simply not be allowed to happen.

PHILOSOPHY OF A HAZARDOUS COMPONENT SAFETY DATA SHEET

By: Edmund Demberg, Safety
Office, US Army Armament
Research & Development Command

Those of us engaged in some facet of ammunition and explosives are quite aware of the inherent hazards involved in the handling, shipping or storage of the product we deal with. Although we depend on safety to remind us of the dangers, we would not deem it possible that someone could get engaged in an explosive operation without prior knowledge of the hazards presented. That, however, is a major contention in establishing liability arising from an industrial accident on a hazardous item contract. Hazardous item contracts are those requiring the research, development, manufacturing, loading, testing and handling of ammunition, explosives and other unique military related dangerous materials.

The US Government, as part of its Joint Conventional Ammunition Program, adapted an existing army program to present safety data on hazardous item contracts. The regulations established a Hazardous Component Safety Data Sheet (HCSDS) as a format for the presentation of the safety data. A HCSDS would be prepared for every hazardous item and every hazardous material, component and sub-assembly that forms a part of or is involved in the production/procurement of the hazardous item. The purpose of the HCSDS is to provide adequate information that would alert to the hazards involved in the fulfillment of contract obligations. The HCSDS' are applicable when provided as part of the solicitation or production/procurement package for or involving a hazardous item.

The data presented represents an opinion as the information that best alerts to the hazards associated with the item. Any information provided, or lack thereof does not relieve a contractor of responsibility for personnel, property and the general public. The HCSDS flags the dangers that we, as developers, are aware of. They do not replace applicable safety standards, codes, regulations, etc., but rather, clearly indicate that these documents must be consulted to address the safety hazards presented by the production/procurement package.

The HCSDS covers all hazardous parts of a hazardous item. Their truo value in depicting the dangers in the handling, shipping or storage of a hazardous item is when they are combined into a complete safety data package. This package has a sheet for every raw material that is part of or used in the proucrement/production package. HCSDS' are prepared for explosives, propellants, pyrotechnics, and their ingredients. The assemblies, and/or components, that these materials are loaded into, are covered by additional safety data sheets.

A final sheet is made for the end item (Cartridge, Mine, Bomb, etc.). The hazards that will be encountered can only be determined by a review of all the sheets that make up the safety data package. The examination of the end item HCSDS or any incomplete portion of the package could lead to misunderstanding. A contractor's facilities might not be able to accomodate some portion of the package. He might not have the proper authorization/license to handle certain materials. Soliciatations might have to be renegotiated. It is, therefore, essential that all hazardous materials, components and assemblies be covered in the safety data package.

To accomplish the task of developing a complete safety data package for a hazardous commodity the technical data package (TDP) consisting of the drawings, specifications, procedures, etc., that define the item and form a part of the contract/solicitation is reviewed. All hazardous items (materials, components, assemblies) are identified and annotated. A list of the HCSDS', their identifying numbers and nomenclature and the document referencing the item is generated. In addition, a schematic is created for each item showing the relation of all the parts and their HCSDS' to the item. These documents are made a part of the procurement package to reveal and insure the complete safety data package is included in a procurement package.

A listing of HCSDS', maintained in a central repository, is reviewed to see if HCSDS' are available to meet the requirements of a package. Applicable HCSDS' are reviewed for completeness and correctness. If necessary, the available sheets are updated to reflect new and current information. If a HCSDS is not available to cover some aspect of the package, it is prepared. Safety data for the HCSDS is acquired by a search of existing literature. Where data is not available, a testing program is conducted to obtain it. The completed HCSDS' are put into the central repository and disseminated in applicable contracts. The HCSDS' are coordinated and standardized with all pertinent elements within the Department of Defense.

The data obtained and presented is a combination of sensitivity, toxicity and classification information to alert the contractor to the environment that could activate a item and the result of such an accidental activation. Energetic materials are rated/ordered and compared to familiar materials. The ratings and comparisons provide a better understanding into the problems and/or procedures that may be encountered in handling such materials.

A Hazardous Component Safety Data Sheet is provided with a distinct number. Each of the military services is provided with a block of numbers to assign to the HCSDS. The HCSDS' are dated and given a revision letter to identify the latest sheets. When no letter appears it is an initial release. Subsequent revisions are given letters A, B, C, and so on. The date reflects the date the original or revision was created.

Our title line contains the nomenclature of the item and is also a means of identification. It is of the utmost importance to understand the significance of this line in order to properly utilize the sheets. The title line spcifies the item whose hazards are characterized by a particular sheet. It does not refer to the materials contained or the final application the item is assembled into. The nomenclature identifiesthe item, containing all its parts, as it comes off an assembly line or out of a blender. An example is a sheet pertaining to the Detonator, Stab, M55. This Detonator contains primer mix, lead azides, and RDX. The HCSDS, however, will deal only with the ingredients when they are loaded into the M55 Detonator and the Detonator is completely assembled (sealed). The HCSDS for each of the encased energetic materials will cover the hazard associated with the loose powders. These sheets, however, will be part of the detonator package. In addition, the M55 Detonator sheet will not pertain to the item when loaded into a fuze. The HCSDS pertaining to the M55 as well as those covering the ingredients would form a part of the safety data package for the fuze. The HCSDS prepared for the fuze would not be incorporated into the M55 Detonator package.

Once the item is properly identified, its sensitivity to various stimuli are presented. The results of friction, impact and electrostatic discharge tests are specified along with comparible values of familiar materials. If the tests cannot be conducted on the item because of its size, shape, or configuration, a "N/A" (not applicable) is recorded. If "Unknown" is specified for a test result, it signifies the

test is applicable but has not been run and test data is unavailable. In both cases, the sensitivity of the item to the stimuli is not ruled out, it has not as yet been determined. The HCSDS prepared at ARRADCOM will generally contain the test results obtained on the apparatus, available at the Command. Any apparatus, however, is applicable that does not radically alter the ordering of the materials and where comparison values can be obtained. Friction sensitivity is conducted by exposing a sample to the action of a steel or fiber shoe swinging as a pendulum at the end of a long steel rod. The behavior of the sample is described qualitatively to indicate its reaction to this experience, i.e., the most energetic reaction is explosion, on decreasing order of severity of reactions: snaps, cracks, and unaffected.

The impact sensitivity is determined by subjecting a sample to the action of a falling weight (usually 2 Kilograms). The impact test value is the minimum height at which at least one of the 10 trials results in explosion. The sensitivity to initiation by electrostatic discharge is a measure of the maximum spark energy, in joules, for zero probability of initiation. It is determined by discharging a charged condenser through a needle point electrode through a sample and observing the reaction.

The hazard associated with the item is identified in the subsequent section of the HCSDS. An adjective rating is placed on the sheets to indicate the fire hazard. The adjective is based on the ease of ignition, the difficulty in extinguishing a fire and the propagation of the flame as follows:

Severe: Very flammable and easily ignited. Extremely difficult to extinguish, instantaneous propagation of flame from ignition source (i.e., flammable gases, highly volatile flammable liquids, ethyl ether).

High: Ignitable under normal temperature conditions or rapid burning rate due to own oxygen supply or spontaneously ignites. Requires immediate deluge to extinguish or prevent propagation of flame (propellants, photoflash powders, white phosphorous, acetone, gasoline).

Moderate: Requires heating before ignition can be obtained. Burning rate or propagation of flame is observable and controllable with standard fire fighting procedures (combustible liquids, solid fuels, kerosene).

Low: Difficult to ignite. Requires high temperatures and long exposure. May not sustain burning without continued heating. Material that readily reacts to produce highly flammable mixtures. Slow propagation of flame. Small flame producing items (oxidizers, squibs, rubber, sulfur, linseed oil).

None: NonFlammable. Difficult to react to form flammable mixtures.

This section also includes safety information pertinent to the fire hazards of liquids and materials. Values are presented for the flash point, flammability limits and auto-ignition temperature. The hazardous decomposition products and the type of hazard (fire, explosion, toxicity) they present are specified.

The explosion hazard is indicated by an adjective rating based on susceptability to initiation and severity of the occurence as follows:

Severe: Capable in themselves of detonation or deflagration in mass. Very sensitive to heat, shock, and electrostatic discharge and require precautionary measures to avoid accidental exposure to these stimuli during normal handling operations. (Primary explosives, primer mixtures).

High: Capable in themselves of detonation or deflagration. Relatively insensitive to heat, shock, or electrostatic discharge. Generally require strong initiating source or heating under confinement to detonate in mass. Explosion presents extreme hazard from blast and/or fragments. (Secondary explosives, bombs, mines, grenades).

Moderate: Not capable in themselves of detonation. Can readily react to form explosive mixtures. Explosion can occur from rapid deflagration of mists or dusts. (Powerful oxidizing material, magnesium powder, flammable gases, highly volatile liquids).

Low: Not capable of detonation or deflagration. Becomes unstable at elevated pressures and temperatures. Package amount, or form prevents or contains release of any substantial amount of energy. Can react to form hazardous mixtures. (Oxidizers, most metallic powders, combustible materials, explosive bellows, piston actuator).

None: Not capable of detonation, deflagration or reaction to form explosive mixes. Stable even at elevate temperatures.

Supporting information for the explosion hazard is furnished as values for explosion temperature (5 sec) and dust. The explosion temperature is a determination of the temperature that produces explosion, ignition or decomposition of a sample in 5 seconds. The temperature and the reaction are recorded. A 0.02 gram sample of explosive is loose loaded into a hot bath (woods metal). The concentration of a cloud of material that will sustain propagation of flame is recorded for dusts.

The toxic hazard of a material is recorded as an adjective rating to express the toxicity under normal conditions of handling and exposure (and including mode of entry) as follows:

Severe: Can cause death or serious injury with exposure of relatively longer periods of time or intake of small amounts. Requires protective clothing and procedures to avoid contact. Prompt medical attention is required. Medical surveillance may be a requirement.

Moderate: Can cause injury, incapacitation, or possible death with sustained exposure or intake of substantial amounts, concentrations, and durations of exposure have to be controlled. Protective clothing and procedures are recommenaed but may not be required. Prompt removal or neutralization of contacted area may may be required to prevent injury.

Low: Can cause only minor injury, irritation, or discomfort. Removal from exposure generally alleviates condition. Cleanliness, ventilation, and protective clothing may be employed to limit or avoid exposure.

None: Presents no health hazard under ordinary conditions.

The following area of the HCSDS deals with the in-process hazard classification. In-process classification is based on the basic item as it exists and is shown on the title line. The in-process hazard is defined as the hazard presented by the item shown in the title while it is unpacked and being handled, not the hazard associated with making the item. Hazard classification while making the item is covered by supporting HCSDS' for each specific ingredient, component, composition/mixture, material, assembly, etc. The in-process hazard classification may or may not be the same. The packaging for an item may change the hazard classification. The in-process hazard classification is to be identified (except for liquid propellants) as follows:

Class 1.1	Mass Detonating
Class 1.3	Mass Fire
Class 1.4	Moderate Fire, No Blast

The in-process hazard classification is to be identified for liquid propellants as follows:

Group IV	Mass Detonating
Group II	Strong Oxidizers, Serious Fires
Group I	Least (Fire) Hazard

The special requirements section is a catch all for any information necessary to identify the item and the hazards that are not adequately presented in the other areas of the HCSDS. This section includes such information as follows:

(a) Reference to document(s) that control and specify item (i.e., drawing, specification) if not already specified in title of sheet.

(b) Schematic/list of parts contained in specified item with HCSDS and drawing/specification numbers.

(c) Any special precautions particular to the specified item not appearing anywhere else in TDP or production/procurement package or in applicable safety manual.

(d) Any additional data/information necessary to alert to or clarify a specific hazard.

(e) Any synonyms that can be used to describe the specified item (i.e., chemical name/formula, commercial brand name, federal stock numbers) associated with the item (i.e., T, M, MK).

(f) Approved packaging drawings numbers. If there are no approved packaging drawings, indicate this fact and indicate where packaging is covered (i.e., specification, provisional packing number). If packaging is not officially covered, the classifications for shipping/storage shall be specified for intra-plant shipping/storage only to meet in-process requirements.

The final information furnished is the storage and shipping classifications. It is just about the only part of the HCSDS that may be mandatory when included into a contract. The storage values are based on the uno quantity-distance classes and divisions and the compatibility groupings. The shipping class and container markings are those authorized by Title 49 Code of Federal Regulations, Parts 100-199.

To briefly summarize, the HCSDS' are incorporated into a hazardous items contract to alert to the hazard involved in the handling, shipping, and storage of hazardous materials, components and assemblies. The HCSDS' are applicable when the complete safety data package (a HCSDS for every hazardous item) is incorporated into a contract. Safety data presented allows for the ordering of energetic materials and their comparison with familiar materials. The complete safety data package should allow a contractor to assess the hazards involved in a contract. Contractors should utilize all applicable safety standards to provide protection for their personnel and property from hazards involved in contract.

MAJOR COMPONENT SAFETY DATA STATEMENT

HAZARDS?

MAJOR COMPONENT SAFETY DATA STATEMENT

REGULATIONS

- DARCOM 385-17
- ARRADCOM SUPPLEMENT 1

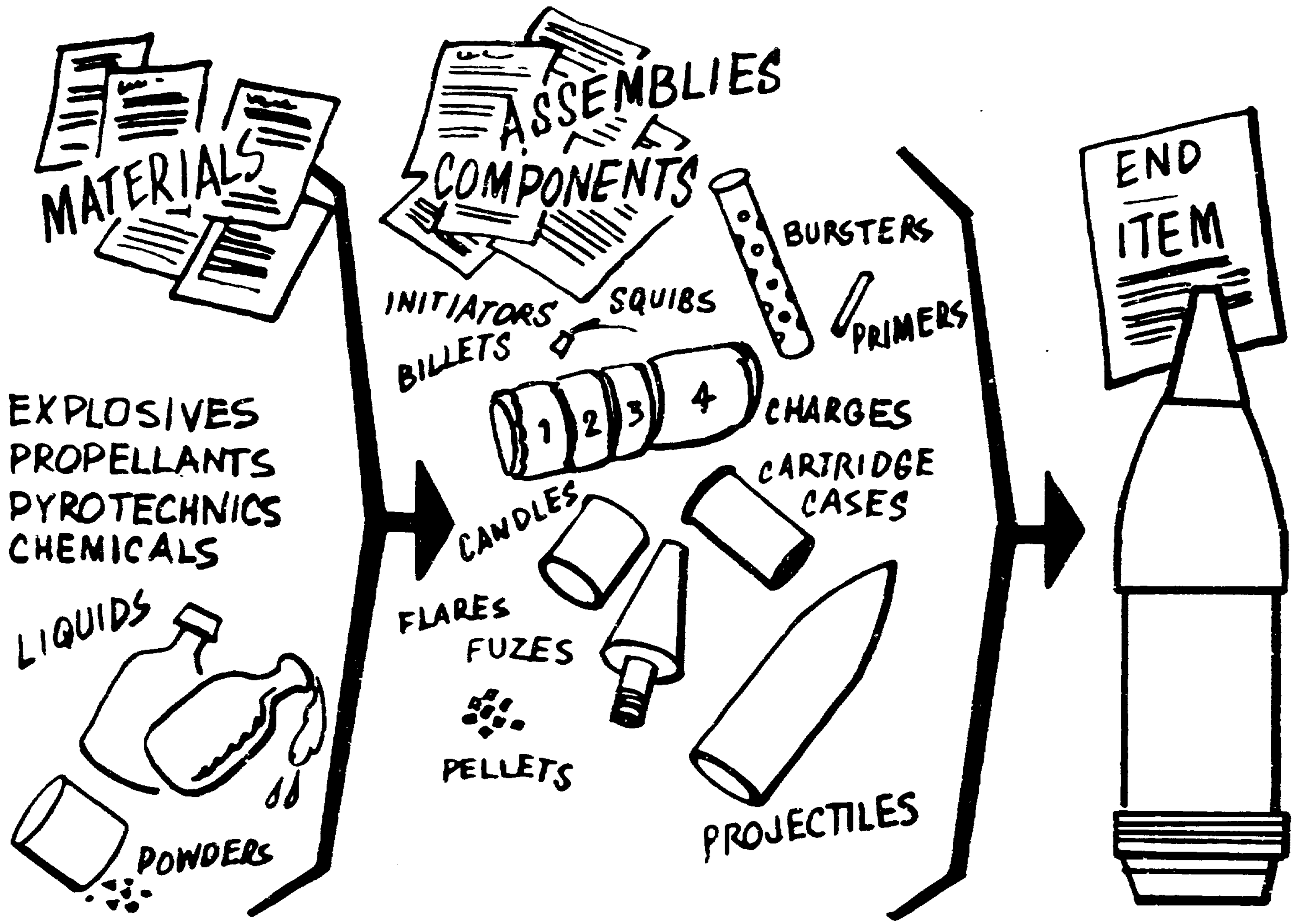
MAJOR COMPONENT SAFETY DATA STATEMENT

PREPARATION PROCEDURES

- REVIEW TDP
- DETERMINE HAZARDOUS MATERIALS
- PREPARE MCSDS LIST
- PREPARE SCHEMATIC
- REVIEW AND/OR PREPARE MCSDS
    - LITERATURE SEARCH
    - TESTING
- TYPE-REPRODUCE-FILE-FORWARD
- STANDARDIZE
- COORDINATE

MAJOR COMPONENT SAFETY DATA STATEMENT

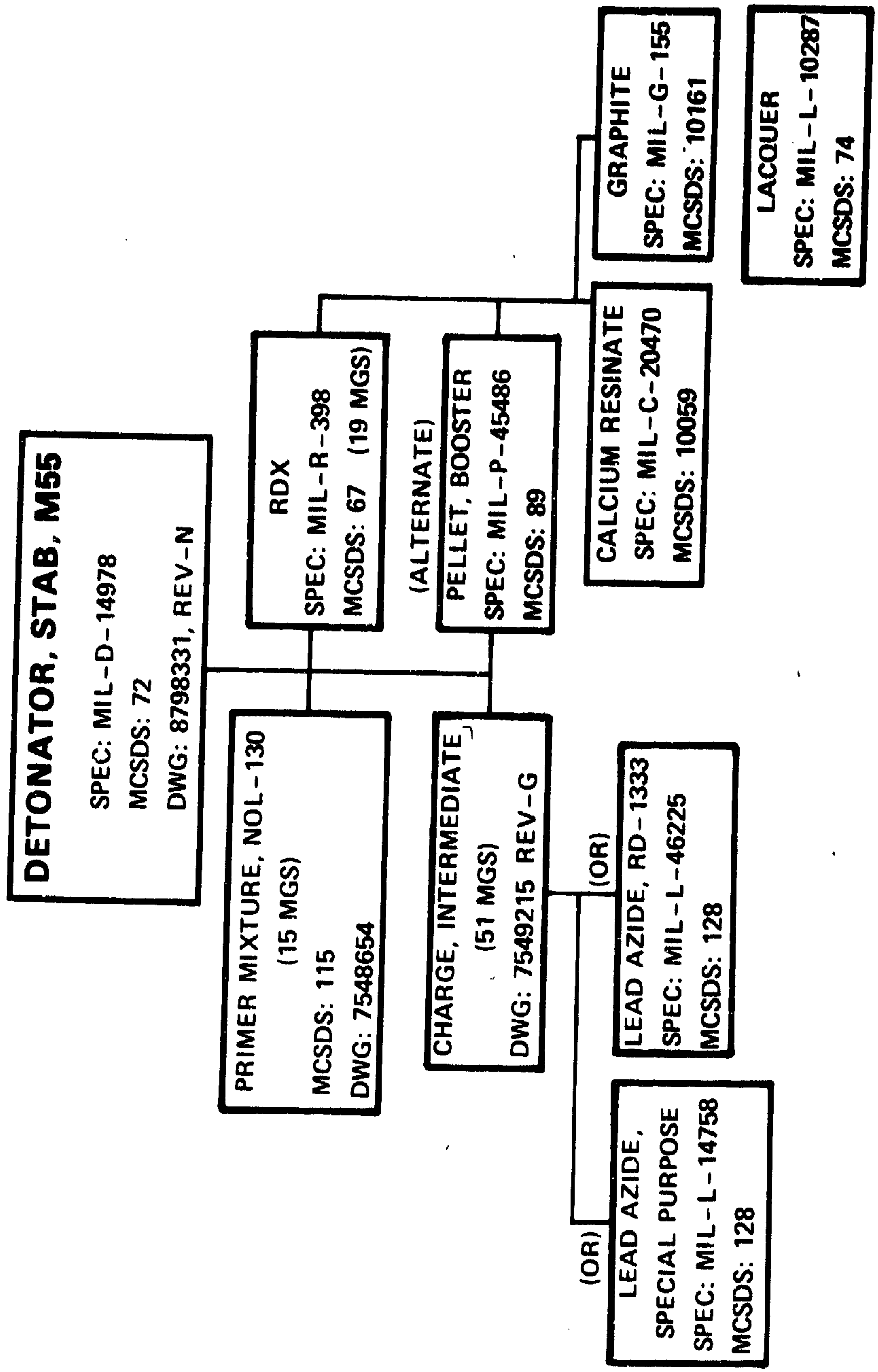
THE SAFETY DATA PACKAGE



MAJOR COMPONENT SAFETY DATA STATEMENT

DETONATOR, STAB, M55

MCSDS	REFERENCE	NOMENCLATURE
72	8798331	DETONATOR, STAB, M55
115	7548654	PRIMER MIXTURE, NOL-130
4	MIL-B-162	BARIUM NITRATE
16	MIL-L-16355	LEAD STYPHNATE
17	MIL-A-159	ANTIMONY SULFIDE
18	MIL-T-46938	TETRACENE
66	MIL-L-3055	LEAD AZIDE
128	MIL-L-46225	LEAD AZIDE, RD-1333
128	MIL-L-14758	LEAD AZIDE, SPECIAL PURPOSE
67	MIL-R-398	RDX
74	MIL-L-10287	LACQUER
89	8841279	PELLET BOOSTER, RDX
10059	MIL-C-20470	CALCIUM RESINATE
10161	MIL-C-155	GRAPHITE


DETONATOR, STAB, M55
SPEC: MIL-D-14978
MCSDS: 72
DWG: 8798331, REV-N
RDX
SPEC: MIL-R-398
MCSDS: 67 (19 MGS)
(ALTERNATE)
PELLET, BOOSTER
SPEC: MIL-P-45486
MCSDS: 89
CALCIUM RESINATE
SPEC: MIL-C-20470
MCSDS: 10059
GRAPHITE
SPEC: MIL-G-155
MCSDS: 10161
LACQUER
SPEC: MIL-L-10287
MCSDS: 74
PRIMER MIXTURE, NOL-130
(15 MGS)
MCSDS: 115
DWG: 7548654
CHARGE, INTERMEDIATE
(51 MGS)
DWG: 7549215 REV-G
(OR)
LEAD AZIDE, RD-1333
SPEC: MIL-L-46225
MCSDS: 128
(OR)
LEAD AZIDE,
SPECIAL PURPOSE
SPEC: MIL-L-14758
MCSDS: 128

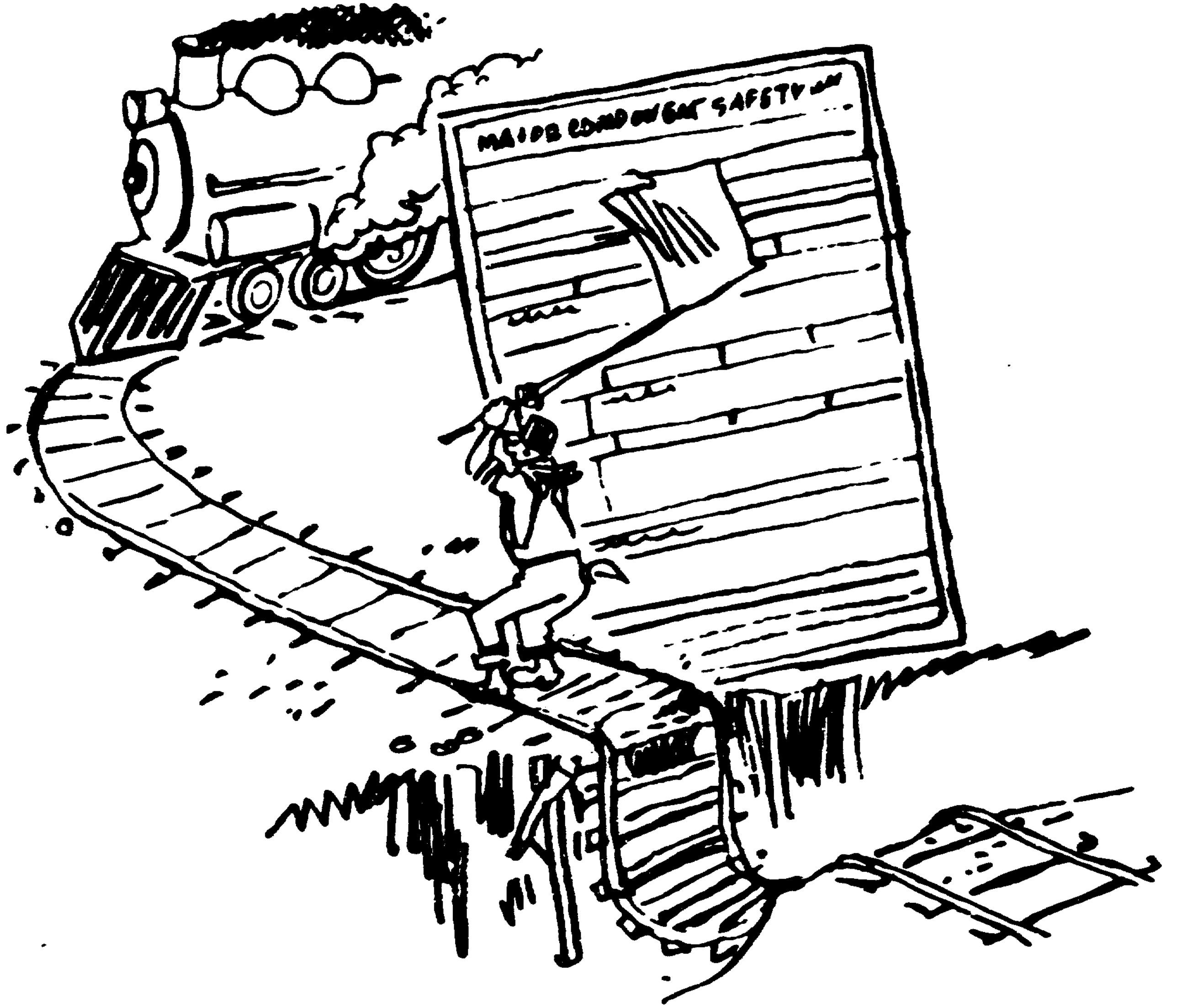
MAJOR COMPONENT SAFETY DATA STATEMENT

TESTING PROGRAM REQUIREMENTS

- IMPACT SENSITIVITY
- FRICTION SENSITIVITY
- AUTO IGNITION TEMP
- EXPLOSION TEMP
- TOXICITY
- FLASH POINT
- FLAMMABLE & EXPLOSION LIMITS
- HAZARD CLASSIFICATION TESTS
- IN PROCESS HAZARD TESTS
- ELECTROSTATIC DISCHARGE TEST

MAJOR COMPONENT SAFETY DATA STATEMENT

FLAGS THE HAZARDS



MAJOR COMPONENT SAFETY DATA STATEMENT

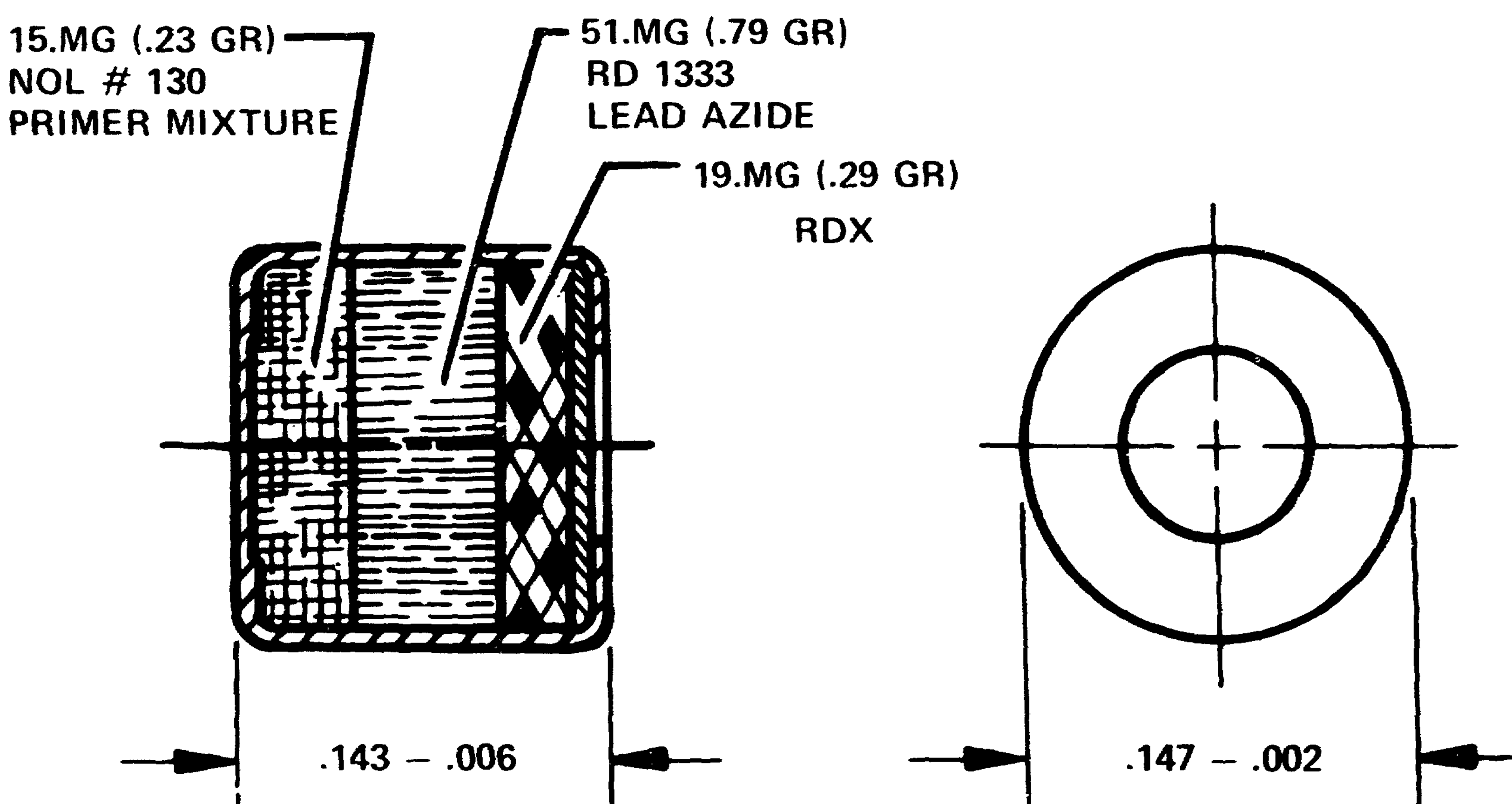
NUMBER ______

MATERIAL/COMPONENT/ASSEMBLY ______________________________

REVISION ______

DATE ______

M55 STAB DETONATOR (MK 95)



MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

STATEMENT OF SAFETY INFORMATION

- SENSITIVITY
  - PA FRICTION TEST
    - FIBER SHOE ______________
    - STEEL FIBER ______________
- PA IMPACT TEST ______________________________

  (FOR COMPARISON –LEAD AZIDE 3";
  TNT 14"; RDX 8"
- BUREAU OF MINES TEST ELECTROSTATIC DISCHARGE ______
  (FOR COMPARISON–LEAD AZIDE 0.0070 JOULES;
  IGNITER COMP 0.21 JOULES; BLACK POWDER >12.5 JOULES)

MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

HAZARDS

FIRE ______________________

- FLASH POINT SOLVENTS ______________________
- AUTO IGNITION TEMP __________ MICRON SIZE __________
- COMBUSTION PRODUCTS ______________________
- FLAMMABLE LIMITS: VAPOR–AIR MIX ____ LOWER ____%; UPPER ____%

MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

EXPLOSION ______________________________

- EXPLOSIVE LIMITS: VAPOR–AIR MIX ____ LOWER ____%; UPPER ____%
  DUSTS ________________
- EXPLOSION TEMP ______________________ 5 SEC

MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

TOXIC ______________________________

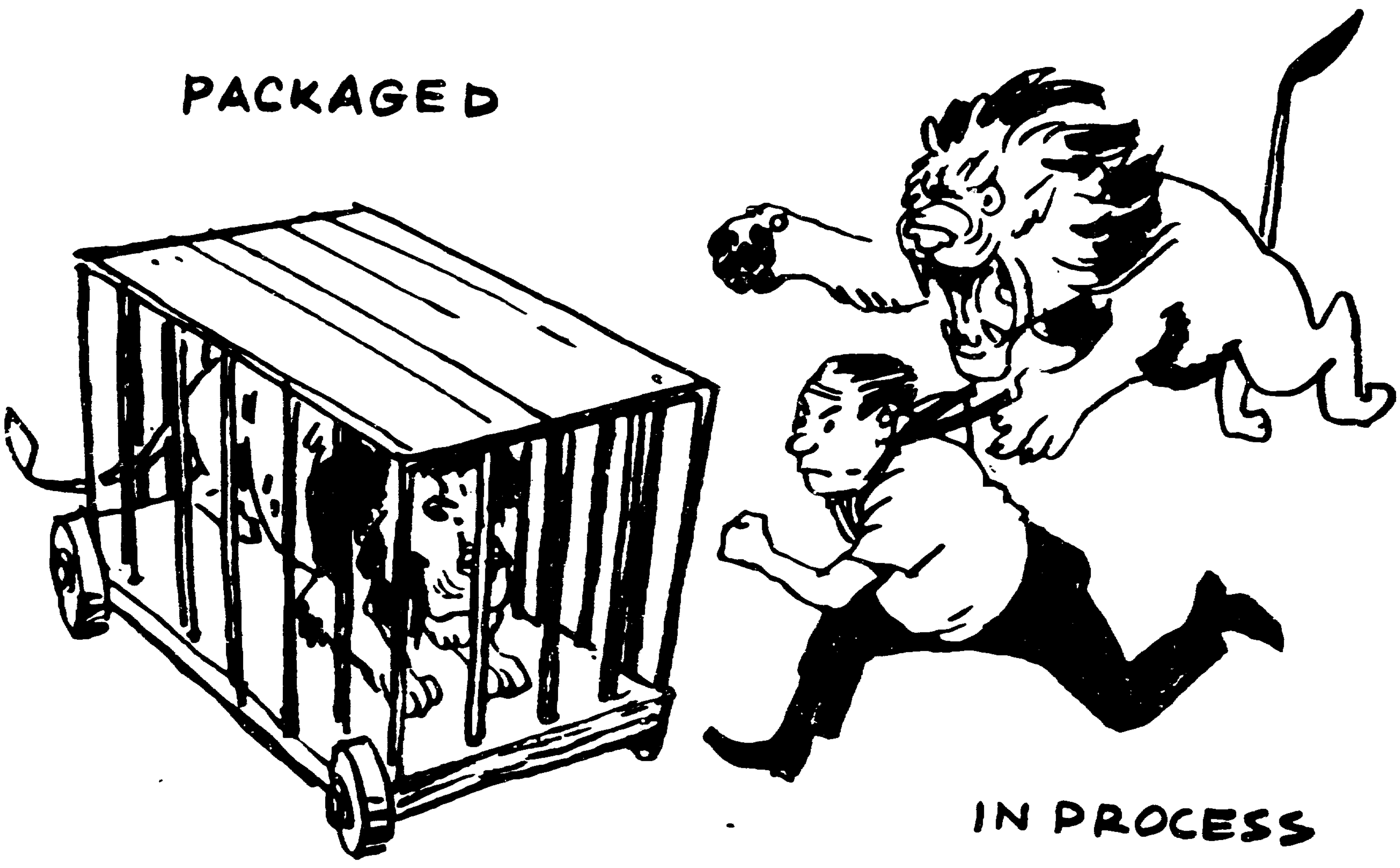
____

MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

- IN PROCESS HAZARD CLASSIFICATION

MAJOR COMPONENT SAFETY DATA STATEMENT

HAZARDS



MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

- SPECIAL REQUIREMENTS: (USE CONTINUATION SHEET)

MAJOR COMPONENT SAFETY DATA STATEMENTS

SPECIAL REQUIREMENTS

GENERAL:

- HAZARDS NOT PRESENTED

SPECIFIC:

- REFERENCES
- APPROVED PACKAGING
- ADDITIONAL DATA
- APPLICABLE STANDARDS AND CODES
- SUPPLEMENTAL SHEETS
- SPECIAL CAUTIONS
- SPECIAL SHIPPING PERMITS

MAJOR COMPONENT SAFETY DATA STATEMENT (CONT'D)

SHIPPING/STORAGE CLASSIFICATION OF ITEM WHEN PACKAGED IN ACCORDANCE WITH APPROVED PACKING DRAWINGS

- DOD HAZARD CLASS ____________________
- DOD COMPATIBILITY GROUP ____________
- DOT BILL OF LADING CLASS ____________
- DOT CONTAINER MARKING ______________

CONVERSION FROM SUPERCEDED HAZARD CLASSIFICATION SYSTEM TO NEW SYSTEM

SUPERCEDED HAZARD CLASS	HAZARD CLASS AND DIVISION
8	6.1
7	(XX) 1.1
6	(18) 1.2
5	(12) 1.2
4	(08) 1.2
3	(04) 1.2
2	(XX) 1.3
1	1.4

MAJOR COMPONENT SAFETY DATA STATEMENT

ADDITIONAL FUNCTIONS

- CONTRACT TRACEABILITY
- COMPUTERIZATION
- HAZARD CLASSIFICATION TESTS

RANGE CLEARANCE TECHNOLOGY

By
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The purpose of this paper is to present an update of current technology being developed by NAVEODFAC as part of our joint service mission and also outline both immediate and future needs involving range clearance equipment and techniques.

Keenly aware of the major hurdles and effort required to establish a viable technology base in which to cope with current and future range clearance needs, NAVEODFAC as directed through higher commands has established a Range Clearance Planning Group. This group has since formulated a plan with the primary goals of establishing a functional technology group and commence a broad based development/acquisition effort to assemble equipment and technology necessary to provide support for all range clearance operations within DoD. This approach, which will be a continuing effort into the 1990's, sets down a cost effective and systematic means to meet future requirements both on land and underwater.

The process of clearing a range can be broken down into technology elements and study areas which include:

- *a. Range survey/reconnaissance.*
- *b. Risk assessment.*
- *c. Clearance equipment/procedures.*
  - *1. Surface*
  - *2. Subsurface*
  - *3. Underwater*
  - *4. Sub-bottom*
- *d. Ordnance/debris demil/disposal.*
- *e. Reclamation.*

The range survey and reconnaissance aspects are the important input to the planning of the operation and eventual outcome. Hopefully not being redundant when discussing the multifaceted problems which appear all encompassing, objectives of an effective survey are to estimate:

1. *Terrain features (influences accessibility and equipment use).*
2. *Vegetation/ground cover.*
3. *Soil composition.*
4. *Type contamination.*
5. *Profile of contamination.*
6. *Special environmental considerations.*
7. *Conditions effecting location equipment.*

Equipment needed for location, marking and plotting of subsurface ordnance items should be intergrated into a complete system. The fielded AN/PSS-11 metal detector and the recently approved MK 22 Ordnance Locator are the only systems presently available. By ensuring the best available location systems are available, the work involved in range clearance can be optimized. The technology that must be addressed for the capability include:

a. Both ferrous and non-ferrous detection.

b. Overcoming the "masking" effects of natural background signatures or those attributed to "trash".

c. Detection of small items (fuze components, detonators, etc.) at the specified clearance depths.

d. Ganging sensors to scrutinize larger areas.

e. Integrating a positioning/navigational and marking system.

Being able to assess the risk of any particular level of contamination with regards to personnel and equipment is a tough one. Essentially the ideal solution is the answer to the question, "How dangerous is a variety of ordnance in an unknown condition?" Depending upon the type equipment that is available for clearance and other projected environmental constraints it will be necessary to develop procedures and logic assessments criteria on which an operational plan is based.

With the data and analytical results from the survey/reconnaissance and risk assessment which will always contain a certain degree of uncertainty, the clearance plan is formulated. The specialized technology needed in order to support any subsurface clearance operation is quite dependent upon the terrain, depth of clearance, hazards of the UXO's and logistical and environmental constraints.

The specific projects which can relate directly to range clearance in which NAVEODFAC is presently pursuing are:

a. Ferrous Ordnance Locator (MK 22).

b. Area Point Search System (APSS).

c. Underwater Excavator.

d. Remore Control System in heavy equipment.

e. Subsurface Clearance Vehicle.

The MK 22 Ordnance Locator is a hand held system which is based upon a cesium-vapor magnetometer. It provides a significant improvement over existing equipment in locating ordnance buried at great depths. This equipment recently received approval for service use and is being considered for use in a towed multiple sensor arrangement for both surface and underwater use.

MK 22 Ordnance Locator

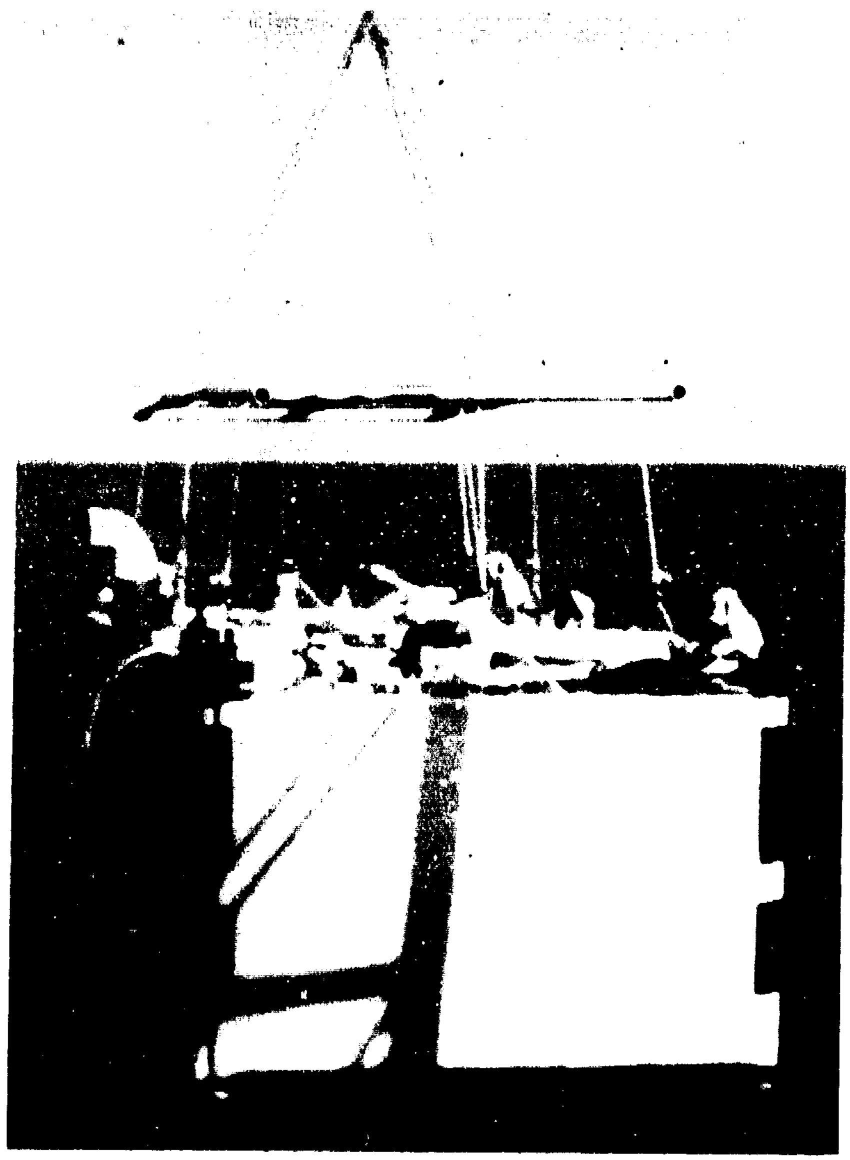
The APSS is an underwater system which provides a means to locate underwater ordnance. The system consists of:

a. Navigation and Data Handling Subsystems which is a line of sight, RF device used to guide search sensors along programmed lanes or to return to predetermined points in the search area.

b. Underwater towed sensors (side scan and magnetometer).

c. Diver held magnetometer type locator.

The underwater excavator is a system used to explore ordnance items which are buried down to three feet in the bottom at water depths over 100 feet. The equipment utilizes a unique combination of jetting and suction action to remove bottom soil.



Prototype Underwater Excavator

Substantial effort has been expended on the development of a surface/subsurface clearance vehicle (SSCV) and a radio remote control system for heavy earth moving equipment.

The following discussion, which is also contained in the brief film, provides a description of the equipment and evaluation results.

Results of numerous range clearance studies and operation clearly focused in on a technology requirement that would support the EOD community when confronted with subsurface range clearance tasks. An approach which proved feasible is the SSCV which is a mechanized system designed to excavate contaminated soil, and separate ordnance debris from the soil. The primary advantages of the concept include:

a. Eliminate existing labor intensive operations.

b. Effective in areas where ordnance detectors are not feasible due to the high level of contamination (masking) or where material magnetic environment is high (e.g., Kahoolawe Island).

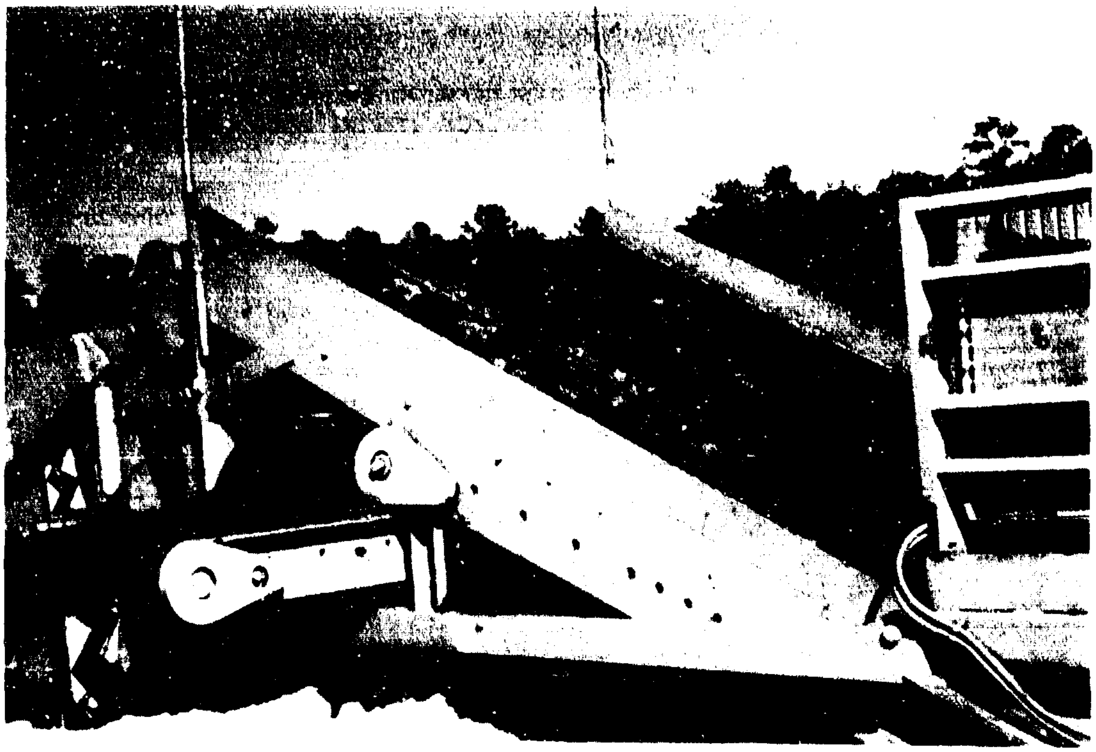
c. Capable of clearing non-ferrous items (e.g., lead mini-bombs, aluminum cased items, plastic munitions).

d. Eliminates human error in that once soil is processed, further searching is not required.

e. Can be remotely operated insuring a high degree of personal safety.

(1) The first generation prototype vehicle was tested at the Pinecastle Electronic Warfare Range (PEWR), Astor, Florida, during August and November 1976. The testing illustrated the approach to be feasible under near ideal conditions. The vehicle was a modified commerical system and proved not to be a viable basis for the EOD scenario. Serious design deficiencies were encountered mainly in the mechanical drive train and wheeled undercarriage. Details on the prototype are available in NAVEODFAC Technical Report TR-184 dated August 1977.

(2) The second generation prototype vehicle incorporating a hydraulic power system was tested at Putnam Target Range during the period of October 1977 through February 1978. Conditions at Putnam were less than ideal. Heavy practice ordnance contamination and varying soil conditions (sandy clay to heavy wet silt) existed. Although structural design and hydraulic deficiencies were noted, the vehicle proved to be effective in digging to a depth of six inches, at a .9 kph (1/2 mph) forward speed, in loose silt to moist sand.



Surface/Subsurface Clearance Vehicle

The advanced development effort presently in the planning stage will involve a third generation vehicle and will include the following features and characteristics:

a. Dig to a predetermined soil depth at a suitable forward speed (no greater than 1 mph). Digging depth is a function of soil properties, degree os contamination and debris, power of primemover, etc.

b. Separate from the soil items greater than 39mm and up to 155mm in diameter and up to 1.5 meters in length.

c. Collect the separated items in a storage bin and windrow the processed soil to the side.

d. Provide a cutting swath of approximately 3.5 meters (11.5 ft).

e. Process at an average rate of 1200 cubic yards of soil per hour.

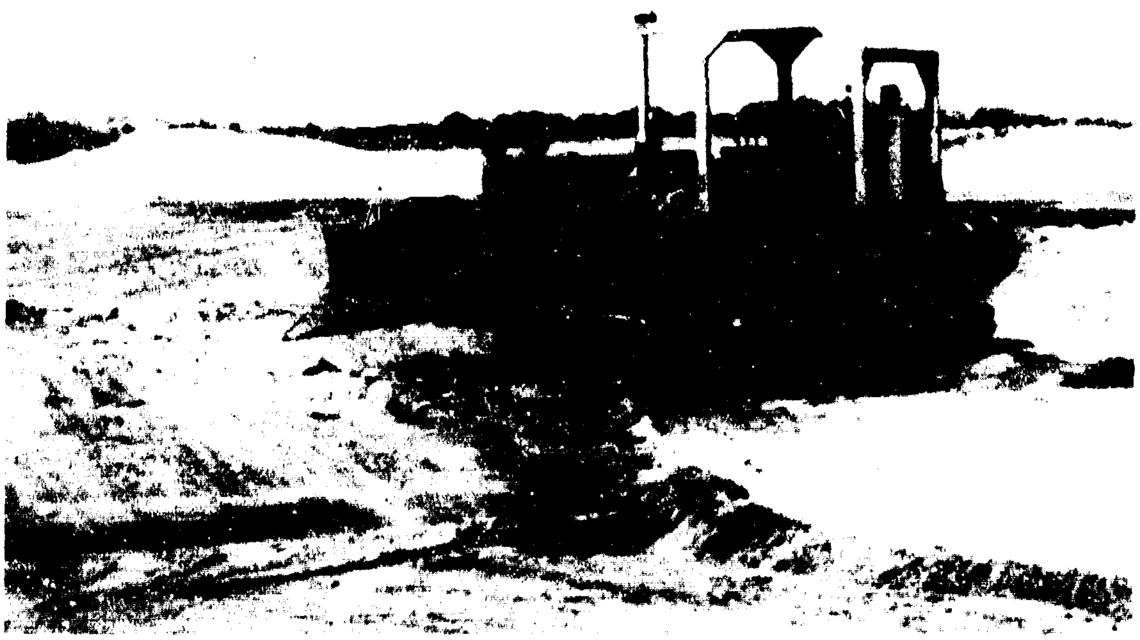
f. Capable of interfacing with remote control and video monitoring equipment for use on ranges in which high explosive hazards exist. The remote control and monitoring equipment will be designed, tested and evaluated as a completely separate development project.

g. Provide limited capability to withstand detonation effects of an explosive device containing 1/2 pound TNT after which most damage will be repairable or components replaced without utilization of depot facilities.

h. Will operate in the temperature range of 52 Deg. C (125 Deg. F) at 5-20 percent RH, 35 Deg. C (95 Deg. F) at 74-99 percent RH and down to 5 Deg. C (40 Deg. F).

A radio remote control system for use on heavy equipment has been designed and tested. With common radio transmitter/receiver components, the prototype system is capable of installation on a TD-20 bulldozer and an M113 Armored Personnel Carrier. Major characteristics include:

a. Line of sight up to 2500 feet.
b. Twenty-four available functions.
c. Six simultaneous functions capable of operating.
d. Man portable transmitter control.
e. Proportional controls.
f. Fail safe features.
g. Mechanical linkage adaptable to heavy vehicle functions.



Radio Remote Control System
Mounted on a TD-20 Bulldozer

RANGE CLEARANCE HIGHLIGHTS

By
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The purpose of this paper is to present an update of the involvement of the Naval Explosive Ordnance Disposal Facility (NAVEODFAC) in supporting joint service range clearance efforts. In interest of completeness, a brief summary of the pertinent material presented during the 18TH DoD Explosive Safety Seminar will be presented after which key highlights of recent range clearance operations and studies will be discussed.

Range clearance is a many faceted problem relating to the removal of Unexploded Ordnance (UXO) from land areas and water/ocean areas. The driving force behind the requirements to decontaminate various areas generally fall into one of the following categories:

1. Return of former battle areas to civilian use, e.g., The Trust Territories and Civil War Combat zones.
2. Turnover of surplus military training and test areas to civilian/nonDoD sectors.
3. Returning leased property to nonDoD owners.
4. Decontamination of government owned land to enable continuance of training/troop maneuver exercises and testing.
5. Revised land use criteria of formerly cleared areas for greater utilization such as, subdivision development, highway construction, or resource extraction.

A quick look at the amount of land areas presently under DoD contract is worthwhile in order to visualize the overall scope.

AGENCY	(Acres) CONUS	(Acres) OVERSEAS
U. S. Army	2.8 million	10,000
U. S. Navy/Marine Corps	2.3 million	23,000
U. S. Air Force	7 million	6,000

When looking at the overall problem, the planning stage is most critical and must be continually addressed. Significant

parameters in the planning effort include:

a. Cost per acre for inert ordnance and debris.

b. Cost per acre for explosive ordnance.

c. Cost per acre based on degree and type of contamination.

d. Cost per acre for varying clearance depths.

e. Cost per acre for varying topography/soil conditions.

f. Impact of climatic conditions.

g. Level of effectiveness acceptable.

When planning and estimating projected costs and most feasible approaches, the basic decision process must address:

a. Is approach suitable in terms of results achieved?

b. Is approach feasible in terms of available equipment, manpower and time?

c. Is approach acceptable from the standpoint of concerned military agency, civilian interests and policical/legal aspects?

Rather than rehashing in general terms the many planning, logistical, political and legal, operational and environmental concerns when faced with a range clearance requirement, it might be best to take a look at recent studies and actual clearance operations.

The following projects have been selected for discussion as representatives which best reflect the overall tasks facing DoD:

a. Kahoolawe Island, Hawaii

b. Blossom Point, Charles County, Maryland

c. Switzerland Bomb Target, Florida

d. Castner Range, Fort Bliss, Texas

e. Putnam Bomb Target, Florida

1. Kahoolawe Island. Located ninety-four miles Southwest of Honolulu, the island consists of over 28,000 acres. It has been used as a target complex since 1941. This essentially uninhabitable island has been receiving an increasing degree of attention and pressure to retain the land for non-military use primarily based upon the fact that it was once a religious site for ancient Hawaiians and contains numerous archeological sites. Several bills sponsored by Senator Inouye were passed in the U. S. Senate dealing with the decontamination of the island and surrounding waters from UXO's.

An extensive survey was conducted in 1976 to determine the feasibility and related costs of clearing the island. AS expected, the area was found to be heavily contaminated with explosive items and cost estimates of clearance as a function of depth soared well over 100 million dollars.

During December 1979 and January 1980, a major investigation was conducted by the U. S. Navy in determining the feasibility and cost of a "surface only" decontamination operation of the eastern one third of the island. The end use of this section was to provide a safe condition for civilians having access to the area with minimum supervision.

The results of the study which utilized "seeded" test items along with those items already on the island proved very interesting. (See Table 1.) The major parameters which were analyzed from the on-site investigation involved personnel and material resources required, clearance rates and effectiveness of search procedures on varying type terrain. Test sites were selected in localities representative of the island's major terrain categories which included those classified as open and fair to poor in terms of trafficability.

Search effectiveness was measured by placing test items in a test area and recording the number of tests items recovered by searchers. Multiple sweeps were conducted to increase search effectiveness and determine affect upon total ordnance recovery. The results of multiple sweeps are outlined in Table 2.

The search technique employed trained EOD technicians walking abreast on a search line visually locating and recovering ordnance like items. Hazardous items were marked and destroyed at the end of each day. The quantity and types of ordnance items recovered are summarized in Table 3.

Search Team on Kahoolawe Island

TABLE 1

SUMMARY OF SURFACE CLEARANCE TESTS

Location: Kahoolawe Island, Hawaii

Search Method: Search Line

Terrain Type Tested (Trafficability	Searcher Spacing Interval (feet)	Search Effectiveness Probability (average)	Search Rate (acres/man day)	Total Area Searched (acres)	Number of Search lanes to cover search area	Ordnance Items Per acre (average)
Open (Good)	22 12	0.84 0.89	4.9 4.1	71 74	5 11	30.6 38.6
Rocky-Bushy (Fair to Poor)	6	0.74	1.2	5.9	3	3.1
	3	0.77	0.7	2.3	3	7.4
Grassy Valley (Fair to Poor)	3	0.52	1.1	8.6	13	17.7

TABLE 2

EFFECT OF MULTIPLE SEARCHES UPON SEP FOR

SEARCH LINE TECHNIQUE USED ON KAHOOLAWE ISLAND

	SEP For One Search	SEP For Two Searches	Percent Increase
Open Terrain			
22 ft interval	82	85	3
12 ft interval	89	96	7
Rocky-Bushy Terrain			
6 ft interval	72	80	8
3 ft interval	79	83	4
Grassy-Valley Terrain			
3 ft interval	52	54	2

TABLE 3

NUMBERS AND TYPES OF ORDNANCE ITEMS FOUND ON

KAHOOLAWE ISLAND DURING SURFACE CLEARANCE TESTING

DECEMBER 1979 - JANUARY 1980

	OPEN TERRAIN	ROCKY-BUSHY TERRAIN	GRASSY-VALLEY TERRAIN
MK 82 Bombs	2	0	0
5 inch Projectiles	49	0	0
5 inch Flare Canisters	21	0	5
2.75 inch Rocket War-heads/motors	20	0	2
MK 76 Practice Bombs	5	0	0
40MM Projectiles	0	0	1
20MM Projectiles	2460	16	33
50 Caliber Projectiles	2404	17	109
7.62MM Ammunition (full-up)	0	0	8
Miscellaneous Components (fuzes, boosters, igniters, etc.)	450	2	0
TOTAL	5419	35	160

It was determined during testing operations that the search line effectiveness could be increased or decreased by varying the interval spacing between searchers. From the test data, theoretical curves were developed to allow surface clearance planners to select the interval size (and inferred number of personnel) with an associated level of effectiveness per terrain type. The theoretical curves and actual test data are illustrated in Table 4. It would be feasible to utilize this type data in the planning of surface clearance operations. By coming to some agreement as to what effectiveness (percent of items recovered) is acceptable, the search interval, number of personnel, and time required are estimated.

Additional testing must be conducted in the fair to poor trafficability areas on Kahoolawe Island as well as other terrains not investigated in an effort to define the total surface clearance capabilities. Different surface clearance methods need to be developed and tested to define the optimum for a given effectiveness and cost. Further studies and follow-on hardware development projects that proved to be needed in the following areas:

1. Location and detection equipment for surface ordnance in areas of heavy vegetation or limited visibility.

2. Retrieval equipment to expedite recovery of ordnance items.

3. Special tools to assist searchers visually hunting for ordnance in high density ground cover.

4. On-site data processing equipment for analysis of search progress and contamination profiles.

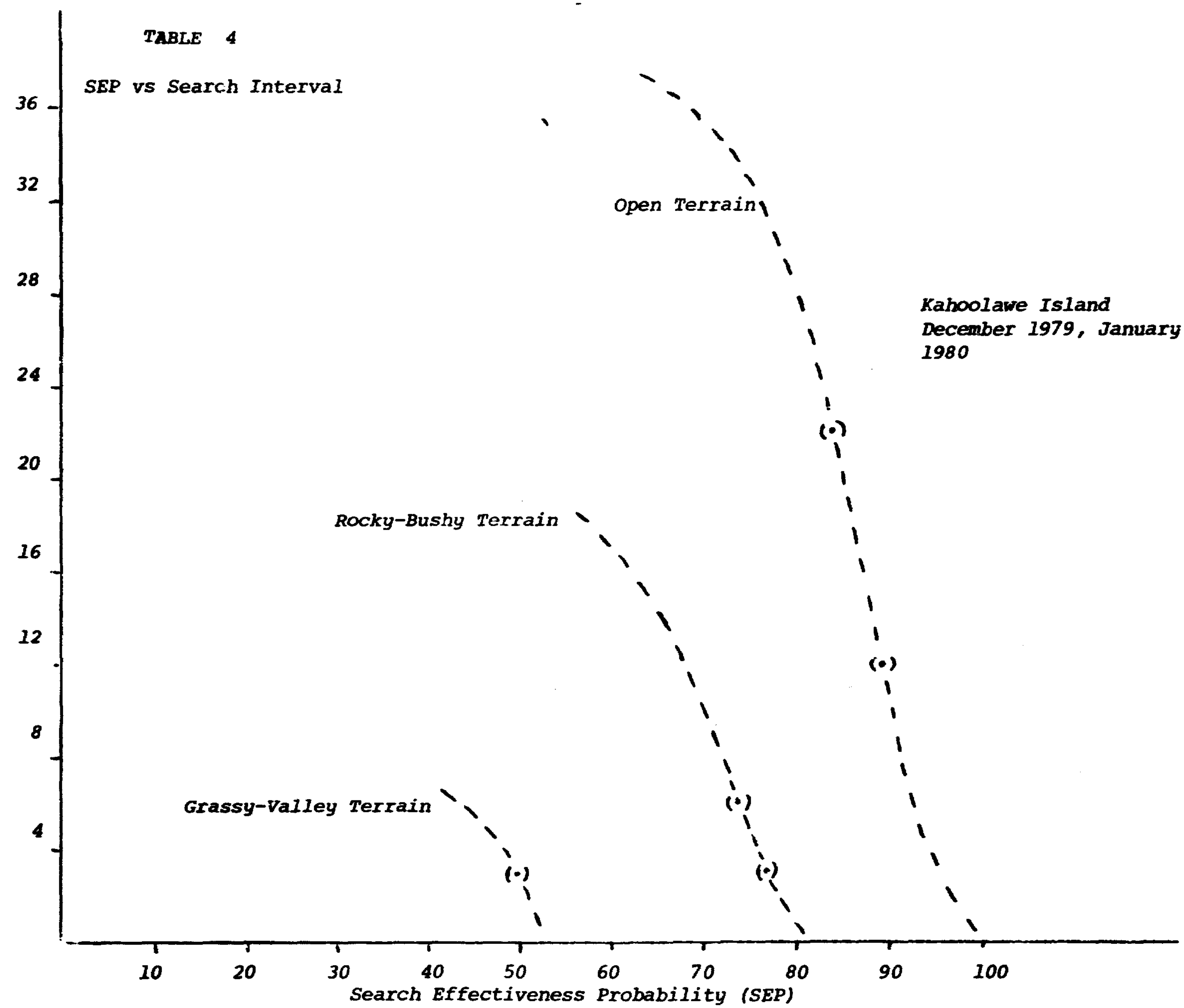
5. Special navigation and positioning system to effectively control clearance operations by accurately marking areas processed.

6. Study of anticipated effects from future errosion of soil and resurfacing of ordnance.

Search Team in Heavy Vegetation on Kahoolawe Island

TABLE 4

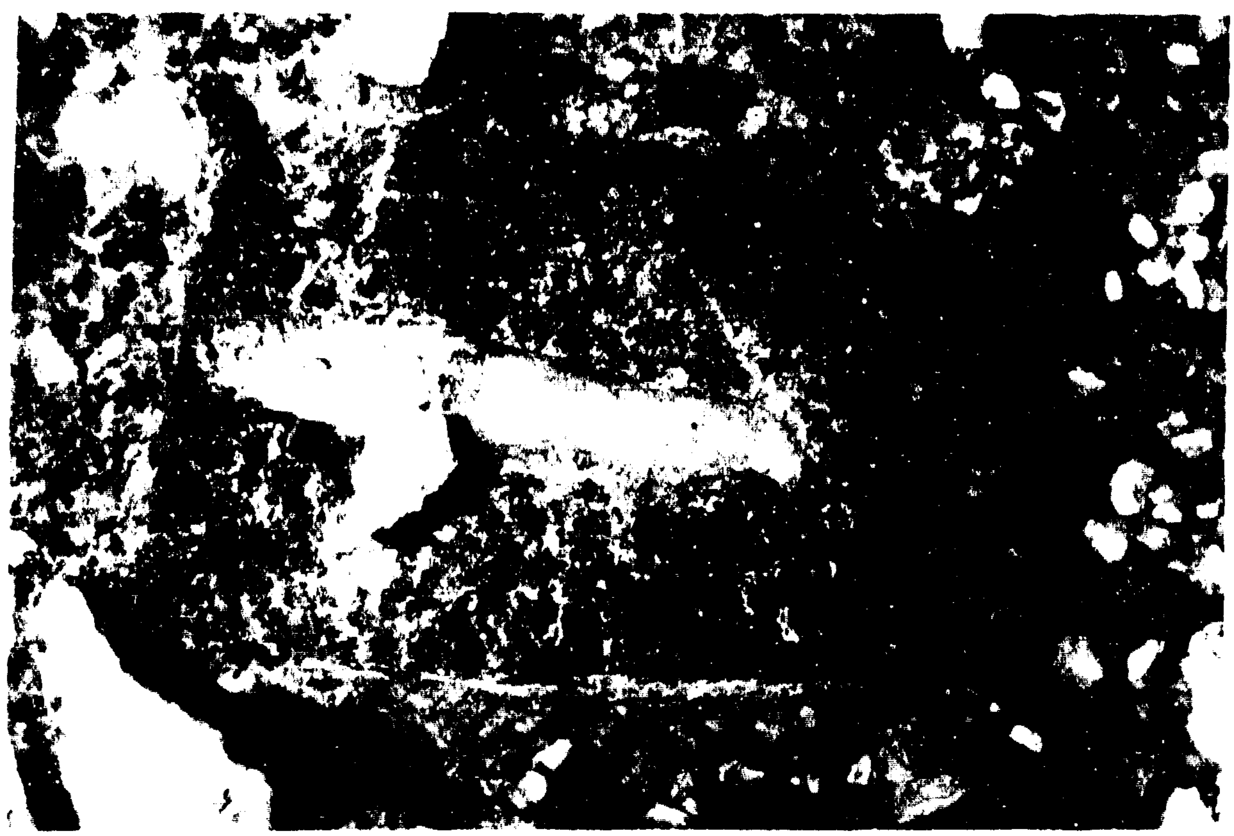
SEP vs Search Interval



2. <u>Switzerland Bomb Target</u>. The Switzerland Bomb Targer is a unique case study in that the land area has long since been turned over to a private enterprise but is receiving substantial attention.

The former Switzerland Bomb Target is comprised of 1782 acres just south of Jacksonville, Florida in St. Johns County. Acquired by the U. S. Navy in 1940 as an auxilliary airfield, it was later designated a practice bomb target. The title was conveyed within a convenant obliging the purchaser to assume all risks for engineers from the Navy's prior use as a bomb target and to indemnify the U. S. Government for all claims which resulted.

The land is now subject to normal development pressures as the locality grows, but any progress toward this end is being effectively blocked by the recorded convenant. Realizing that practice ordnance which contain marking devices such as the MK 4 Smoke Signal can and has proven to be highly dangerous, should an inadvertent functioning occur, the U. S. Navy is not ready to certify the area safe.



MK 4 smoke Signal Exposed in Practice Bomb

Should it be decided that the covenant not be removed unless an extensive subsurface clearance effort is undertaken, the land will always be in a state of "unknown hazardous condition". The possibility exists that the U. S. Navy will be held responsible for any injuries even if the land is not used for residential purposes.

A possible alternative involves a quantitative test program in which the primary goal will be to determine the actual magnitude of the hazards currently existing on the land. This test program would be structured to include the following:

1. Systematic excavation and recovery of a sufficient quality of representative items in which to evaluate with respect to degree of potential hazards.

2. The recovery operation will also serve as a basis as to provide data on the level of contamination relative to the distance from the center of the target bull's-eye.

3. Radiological examination of recovered items in order to determine expended items from those which contain live components.

4. Simulate adverse conditions to determine probability of actuation under impact and in high temperature environment. Essentially, these conditions relate to an innocent party rough handling an item or using a hammer and probe or possibly exposing an item to a camp fire or trash fire.

The results of the test program will provide the following:

1. Percent of duds received. (A dud is defined as an ordnance item which contains an explosive which did not function.)

2. Contamination profile of the target as a function of distance from the target center including an outer limit in which the recovery of additional items is highly unlikely.

3. Most importantly, the percent of items that contain live components which are susceptible to impact or high temperature conditions.

In summary, it is work noting that declaration and transfer of excess ordnance impact property certainly does not eliminate future attention on the part of DoD.

3. Blossom Point. The Blossom Point Test Facility located in Charles County, Maryland is a case worth discussing. Leased by the U. S. Army from the Corporation of Roman Catholic Clergymen of Maryland (Jesuits) since 1942, the land had been extensively used as a testing ground for projectiles, guns and rockets. The terms of the lease specified that upon termination, the property is to be returned in condition comparable to its 1942 state.

The U. S. Army was faced with a serious problem. Namely, the yearly lease fees for 1,600 acres was averaging over $150,000 and projected lease figures of $325.00 per acre into the 1980s.

A study was conducted to determine the feasibility and approximate costs of decontamination. The findings indicated clearance costs into the millions and totally unacceptable ecological consequences. The area located on a peninsula south of Washington, DC on the Potomac River and Nanjemoy Creek contains sandy beaches, wildlife sanctuary, and historic and archeological sites. Needless to say, a subsurface clearance operation would raise havoc at every turn.

In early 1980, the U. S. Army purchased the 1,600 acres for $2,784,000.00 ($1,740 acre) and thereby avoided the lease requirements for decontamination. One need only speculate from other situations what may arise on this subject in the future as the adjacent lands become more developed and government policy changes.

4. Castner Range. Castner Range, Fort Bliss, Texas is an example of the forces of local interests at work because of the need of expanding residential development.

Castner Range is located approximately two miles north of Fort Bliss Military Reservation near the city of El Paso. Figure 1 presents the general location of the range. The original Castner Range contained approximately 3,473 acres and was acquired in 1926. A Deed of Cession was obtained from the state of Texas on 19 October 1928. This acquisition included the site of some firing lines and impact areas in the southern sections of the range. An additional 4,800 acres, completing the present Castner Range area were acquired by purchase in 1939. Throughout the years, a wide variety of ordnance was fired into the impact areas; e.g., Stokes mortar shells, 8-inch coastal artillery shells, and many kinds and calibers of field and air defense artillery. Castner Range was used for live fire operations until 1966. In that year, the City of El Paso acquired a right-of-way through Castner Range for the Transmountain Highway and the North-South Freeway. In exchange, the firing sites were replaced with a new complete facility in New Mexico (The G. Ralph Meyer Range). Due to the low use and the existence of this alternate range facility, Castner range has been declared excess by the U. S. Army.

During 1974, a surface clearing operation was undertaken on a 1,200 acre portion of Castner Range. This area was then turned over to General Services Administration for disposal. Portions of this area are currently being used for a community college. The surface clearance of this area was accomplished in a 650 man-day effort. Five items described as Unidentified Explosive Ordnance (UXO's) were found.

During December 1979, surface sweeps were conducted 200 meters on either side of Transmountain Road and along a two mile section of the North-South Freeway. Forty-nine (49) UXO's were removed. Approximately 90 man days were required to accomplish this clearance. The sweep was accomplished in terrain which was highly treacherous in areas and through areas which, according to the range fan maps, were highly contaminated.

As the result of ever increasing pressure from the City of El Paso and the admitted position that the land is no longer needed by the U. S. Army, studies, discussions and plans are continually on going with the primary goal of conducting sufficient decontamination as to allow the Government to certify the land safe for various uses.

As requested by the Director of Facilities Engineering at Fort Bliss, a three-man survey team was sent in January 1980 to Fort Bliss to provide a quick assessment of the effort required to surface clear Castner Range west of the North-South Freeway.

The area surveyed by the team included portions of all areas which could reasonably be accessed with a 2-wheel drive vehicle. Other portions of the range were visually searched during a helicopter tour of the range.

During the survey, the team found evidence of munitions from 37MM to 3.5-inch rockets. No live or hazardous munitions were found. No large ordnance was found although there was some evidence of shrapnel from 105MM projectiles.

The area surveyed was reasonably flat. Vegetation included short shrubs and cacti. The soil appeared to be shallow sand-gravel with large amounts of stone. The area which the team could not readily access was quite mountainous. Shear cliffs, hundreds of feet high, were in evidence. Little or no vegetation was in evidence. The soil was generally gravel with rock near the mountain peaks.

Although the area had been posted with "DANGER/NO TRESPASSING" signs such warnings are largely ignored by the local populace. There is abundant evidence of public access and use of the property such as camping, target shooting, hunting, etc.

It is considered that a surface sweep is a viable approach based upon the projected use of the land as a wilderness area.

Future liability and legal consideration of this approach is beyond the scope of this paper. However, individuals in responsible positions could be expected to become involved in planning and developing suitable equipment and procedures to effectively decontaminate land of this type should such a situation arise.

5. Putman Bomb Target. *The examples previously discussed involved ranges pending decontamination which clearly illustrate the scope of the problem. An actual clearance operation which is well documented should balance out the purpose of this paper. Approximately twenty minutes of film will be shown on the Putnam Bomb Target operation.*

Putnam Bomb Target, located in Putnam County thirty miles (48 KM) south of Jacksonville, Florida, was acquired by the Navy under leasehold in 1941 for use as a practice range for aerial bombing.

The land owner, Union Camp Corporation of Savannah, Georgia, notified the Navy in October 1976 that the current lease, due to expire 30 June 1977, would not be renewed. Consequently, the range was placed in an inactive status 27 May 1977. The lease stipulated that the Government restore the land to "as good a condition" as that existing on initial possession by the user agency. This stipulation obligated the U. S. Navy, as the user agency, to remove all structures and ordnance contamination which resulted from use of the land as a practice bombing range.

In order to determine the extent of the clearance effort to be expended at Putnam, a planning conference of representatives from all commands concerned was held at NAS Jacksonville in June 1977. As a result of this conference, a discussion with the Union Camp corporation, EODGRU TWO, with support from NAS Jacksonville, was tasked with clearing Putnam Target to a depth of 12 inches (30.5cm).

The Putnam clearance operation was conducted in two phases. Phase I, surface clearance, was accomplished between 15 August and 29 August 1977 be EODGRU TWO personnel with support personnel augmentation and heavy equipment from NAS Jacksonville. A total of 1584 man hours were expended in the recovery of 12,568 items of practice ordnance.

Typical Ordnance Recovered from Putnam Bomb Target

Scrapers in Push-Pull Configuration

Recovery Ordnance During Good Weather

Phase II, the subsurface clearance, commenced on 26 September 1977 and was completed on 22 February 1978. The subsurface clearance involved an expenditure of 32,810 man hours and 5,680 hours of heavy equipment/vehicle usage. One hundred six thousand eight hundred twenty six items of practice ordnance were recovered during subsurface operations for a total of 119,394. All ordnance items and related debris eere staged at Rodman Range, an active target complex thirty miles south of Putnam, awaiting a determination on final disposition.

A summary of related costs is shown below:

Category	Cost
Equipment Rental	$187,283
Military Labor*	205,166
Travel Expenses	106,842
Military equipment & services	95,474
Documentation	70,099
Site Demolition**	25,400
NAS Material**	9,700
EOD Material	12,927
Survey	1,400
Communications**	600
	$714,891

* Estimated cost.
** Estimated cost. No breakdown available.

These costs do not include final disposition of the items stored at Rodman.

Many of the problem areas cited in the operation resulted from the lack of standard guidelines and operational precedents to support Putnam planning. Devleopment of the clearance precedures and associated support requirements was also constrained by personnel and equipment availability. Because the Putnam operation provides a precedent for future planning, any area which was identified as either a problem and/or lesson learned was noted.

The most significant problem encountered during the clearance was weather. Rain caused the operation to extend two months beyond the scheduled finishing date. The rain in combination with freezing weather in January and February reduced the range to a veritable quagmire. The problems involved in operating heavy equipment under these conditions caused frequent cancellations of all range operations. Considering the adverse conditions and problems involved, the clearance of Putnman Targer was a major accomplishment of which all involved can be proud.

Effects of Rainfall
on Operations

Other significant problem areas or lessons learned can be summarized as follows:

1. Range usage data was incomplete--it was not possible to determine the extent of contamination or if live ordnance had been dropped on the range.

2. There is not proven or accepted methodology for estimating contamination.

3. Provisions must be made for area drainage and removal of vegetation/trees prior to the commencement of clearance.

4. The available heavy equipment was employed to maximum effectiveness within design capability. Lack of specialized equipment required the expenditure of excessive man hours for processing soil and collecting debris with the resultant increase in cost.

5. Current ordnance location equipment is not effective in areas with moderate to heavy metallic contaminaiton.

6. Maintenance of heavy equipment and vehicles was also a major problem in the early stages of the operation. Qualified maintenance/repair personnel must be available on-site, properly equipped to perform minor repairs.

7. Special provisions must be made for on-site secure storage of spare parts, consumables and operational equipment.

8. Radio communications were not relaible. A landline installation enhances safety of operations and serves to expedite requests for support.

9. Range access proved to be a significant problem. The need for an all-weather range access road cannot be overemphasized. The road should be prepared prior to the movement of any equipment and maintained in top condition. This will reduce travel time, vehicle repairs and down time and subsequent costs.

The following conclusions were drawn from the operation:

1. The mission objective as stated in the clearance plan "to detect, locate and collect all surface and subsurface ordnance material possible to a depth of 12 inches, "was achieved to the maximum degree possible with currently available equipment.

2. Certification of 100 percent clearance of all items to the 12 inch (30.5cm) depth cannot be granted for Putnam or any other land range, using current techniques and equipment.

3. The cost of mass excavation techniques as employed at Putnam to assure an acceptable degree of clearance is out of proportion to the relative value of the land. The excessive costs are directly attributable to the inordinate number of man hours and heavy equipment hours involved in repetitive soil processing for lack of a suitable alternative method.

4. The historical range data available for Putnam was inadequate to support clearance planning. Previous studies have reached the same conclusions for all Navy impact areas. The information required to support a determination of the type, location and density of range contamination should be continually updated in a central repository for each active target area.

5. If the decontamination of land ranges (all ordnance impact and/or test areas) is to be accomplished using military resources, then appropriate action must be initiated now to develop the specialized equipment and techniques required for efficient and effective clearance operations.

The following recommendations assume continuing military involvement in range clearance--the extent of their implementation should be predicated on the degree of involvement and a determination of service responsibilities. In considering these recommendations, it should be noted that the problems which were encountered at Putnam in the clearance of an inert range would be of a far greater magnitude in a live impact area where safety becomes the overriding issue.

Based on the results of the study it was recommended that:

1. A determination be made as to the responsibility of the Services for clearing land impact areas; this determination should be made in the form of a Joint Service Agreement and a single manager designated for range clearanc.

2. A phased clearance program be implemented to provide for controlled, incremental decontamination of range areas that may be designated as excess to military requirements. The prototype Surface Shallow-Subsurface Clearance Vehicle (SSCV) and other specialized heavy equipment should be assigned to this program for extensive field test and evaluation in live impact areas.

3. Two EOD Facility be designated as the lead laboratory for the development of a Range Clearance System (land) with appropriate support from the Civil Engineering Laboratory, Port Hueneme and other Service development activities as required. Funding for this program should be in the form of a special appropriation to preclude the reapportionment of funds from other EOD development programs.

4. A cumulative data base be maintained on all active range complexes to include specific target/grid usage and daily ordnance expenditures by type. Consideration should be given to the development of a minicomputer based range data information system designed to collect, collate, store and retrieve appropriate data in support of future clearance projects.

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Paper for presentation at the 19th DDESB Explosives Safety Seminar

09-11 September 1980

Title: Portable Self-Contained Deluge Equipment for Propellant Fire Suppression.

Content: Text and pictures, totally 8 pages.

Presented by: Ingvar Rudin, The National Inspectorate of Explosives and Flammables, Sweden.

PORTABLE SELF-CONTAINED DELUGE EQUIPMENT FOR PROPELLANT FIRE SUPPRESSION

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ABSTRACT

Rubricated equipment has during the early seventies been designed in Sweden for use in plant areas where assemblage of ammunition demands limited quantities of propellant in open boxes.

Tests during the development of the extinguisher have shown, that a water quantity of about 150 litres applied to the burning surface sideways and in a gentle flow is sufficient to suppress an accidental fire in propellant kept in an open box with a volume of about 100 litres within two or three seconds.

Experiments made with different sorts of propellent powders have given reason to the supposition, that the equipment is capable of cooling down and suppressing accidental fires in most propellants, even such of very small dimensions as well as of pourous type.

INTRODUCTION

It is well-known that ordinary water deluge systems of common type

cannot extinguish propellant fires, and interest exists for finding ways to complete such installations with arrangements at the very point where propellent powder for technical reasons has to be handled openly.

The above aimed suppression method is the result of an aspiration to design a separate equipment, portable and carrying its own supply of water and entirely independent of fixed installations for water, electricity, compressed air etc.

Accomplished test-series have shown that a box containing about 100 litres of propellent powder ignited from the top has been fully filled with water within 3 seconds.

It has also been noted that propellant fire can continue under the water surface before refrigeration and extinguishing has been fullfilled.

FUNDAMENTEL DESIGN OF THE BASIC MODEL

The equipment consists of following parts

- Water tank, holding 150 litres
- Scuttle with a cirkular opening of 40 sq cm
- Release mechanism
- Water spreader

The water tank is located at the side of and about 10 cm above the box, in this case holding maximally 100 litres.

The scuttle is kept in closed condition by a spindle, which is connected to the release-mechanism placed in the upper part of the water tank.

The release-mechanism is designed to drop the spindle by a coil-spring brought into action at the very moment a connecting piece of nitrated cotton cord between the spring and the propellant is destroyed by the first flames of an accidental fire in the box.

As an alternative or as a complement the scuttle-spindle can be dropped by an electrice impuls from a photo-cell assisted by a suitable kind of explosive train.

When the release-mechanism opens up and the water comes rushing down, the scuttle and the spindle falls to the spreader-bottom without disturbing the flew of the water.

The spreader consists of a curved perforated metal plate which transforms the rushing water to a quick, but calm and smooth flood covering the whole burning surface.

Noted test-results and estimated times

	Photo-cell	Nitrated cotton cord
Time from ignition to open scuttle	0,1 - 0,2 sec	0,3 - 0,7 sec
Time from open scuttle to the water stream hits the propellant	0,2 - 0,45 sec	0,2 - 0,45 sec
Total	0,3 - 0,65 sec	0,5 - 1,15 sec

CONCLUDING REMARKS

A. The basic model for this equipment comes from an idea of the former Safety officer at FFV plant in Åker, engineer Sven Sandberg. In the continued designing work, the head of the plant, chief engineer Rolf Juhlin, has put resources and knowledge to Sandberg's disposal.

B. In case higher speed proves necessary in the release-mechanism it is possible to change from photo-cell to UV-detector in the explosive train. AB Bofors has to that purpose made development work, which has proved successful.

C. Of great importance is, that practical tests are made under identical circumstances with equipment as well as with the propellent powder in question, before the installation comes into use.

D. If several deluge equipments are used in the same area it is essential, that all releasing-mechanisms will be kept synchronized.

E. The presentation of the paper includes film sequences of about 6 minutes run.

FIGURES

1. Principle sketch
2. General view of experimental equipment
3. Release-mechanism from above
4. Water spreader

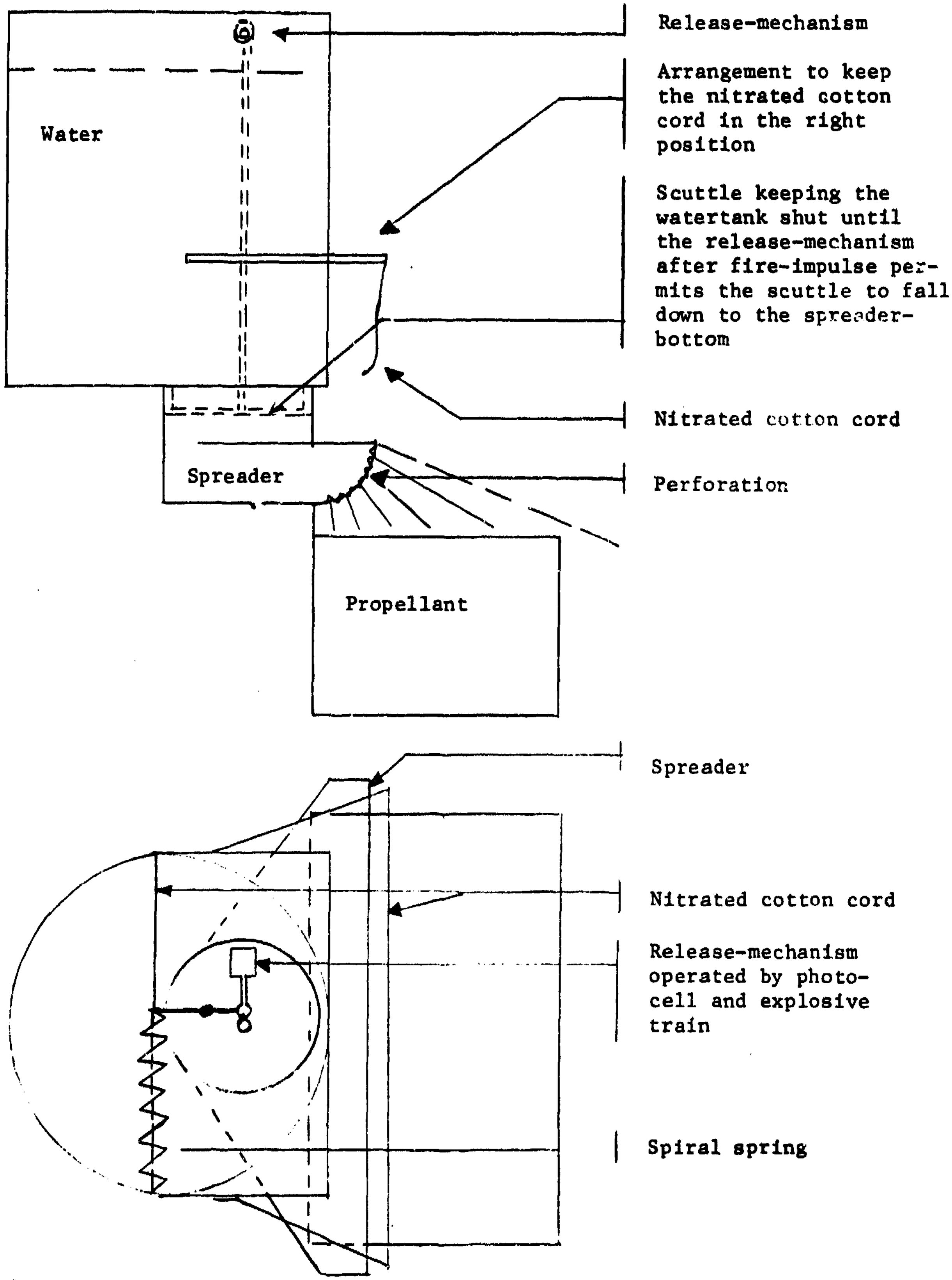
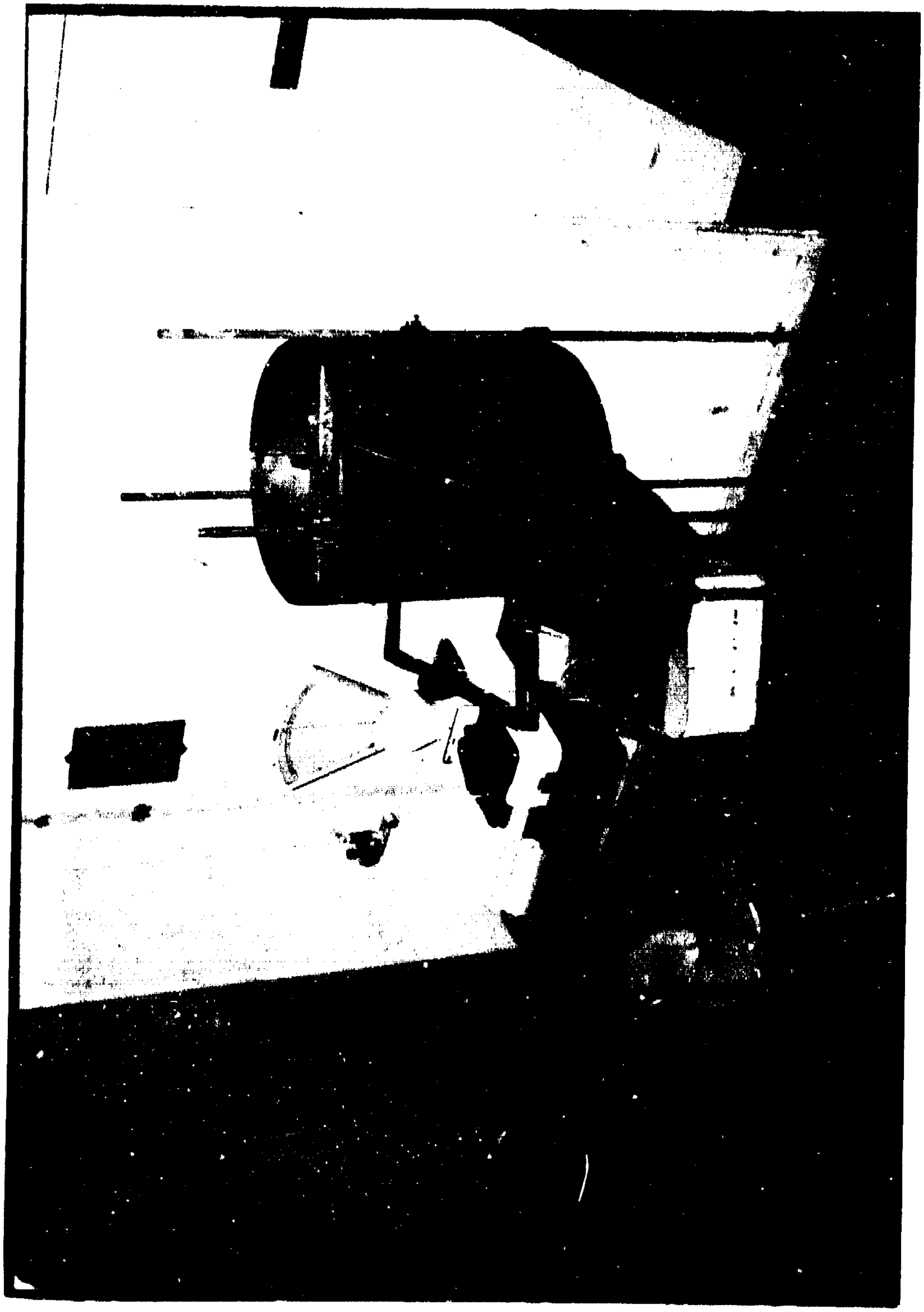
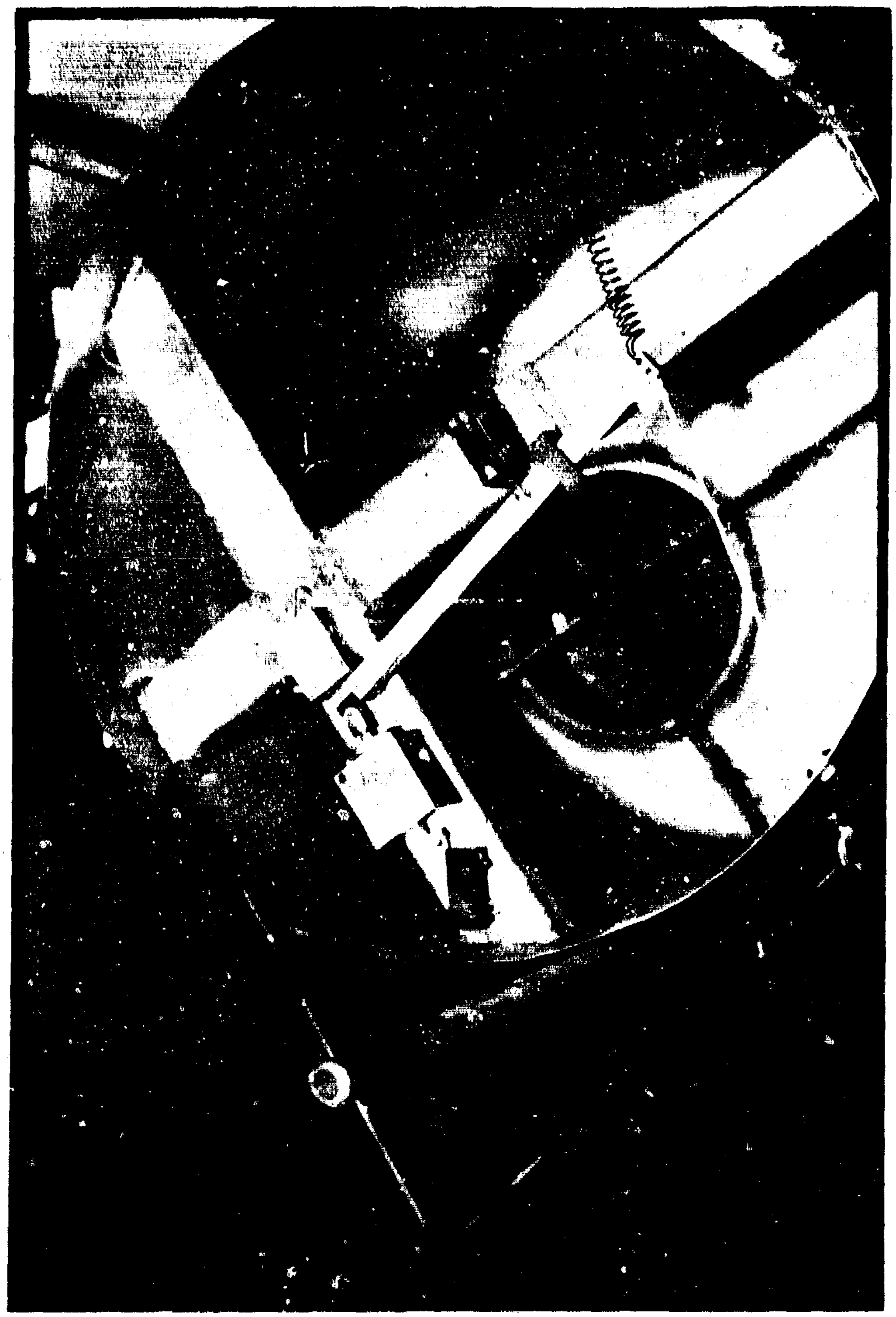


Figure 1.
Principle sketch



2. General view of experimental equipment



3. Release-mechanism from above

Water spreader

Control of Fires in Munitions Areas
Using Water Deluge Systems

A Paper Presented by

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at the

19TH EXPLOSIVES SAFETY SEMINAR
Los Angeles, California

September 11, 1980

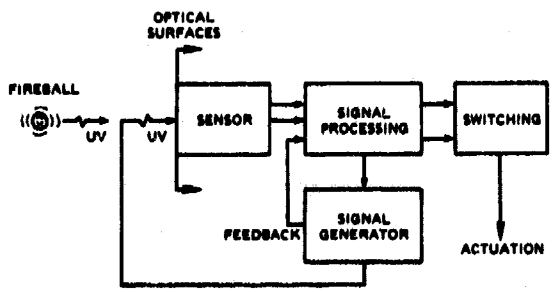
Control of Fires in Munitions Areas Using Water Deluge Systems

Ultraviolet detection devices have come into wide use for the protection of facilities involved in handling munitions materials. Because of their fast response to the presence of flame, they are well suited for applications where fire develops rapidly and presents a major hazard unless it is immediately contained.

Over the years, Det-Tronics has systematically addressed the problems associated with high speed automatic fire protection systems, and we have reported the progress in this field during each of the DDES Seminars held during the last decade. Today we will present a film series showing tests on an advanced water deluge system currently in use by the company Bofors in Sweden, and which is ultimately to be installed for protection of about 400 buildings in Karlskoga. In addition, we will describe a recent innovation in UV detection systems, which we believe represents a significant advance in the field of fire protection. Identified by the term "Remote Surveillance", this new concept can be utilized in munitions applications as well as offshore oil platforms, pipelines and other hazardous industrial processes, to reduce and perhaps ultimately eliminate spurious system response due to radiation coming from outside the controlled fire zone. This includes interference signals from electric arc welding, flare stacks and prolonged lightning flashes.

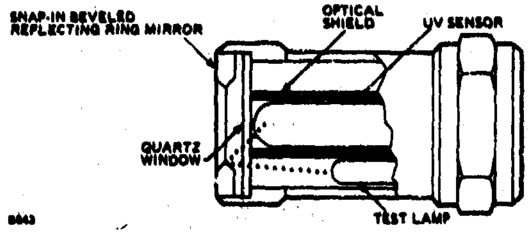
To aid in an understanding of the Bofors film sequence, it will be useful to examine the main components employed in the tests. Slide 1 illustrates the detection system in block diagram form. Note that it consists of an enclosed radiation detector, a power supply and signal processing electronic package, an output switching means, and an optical feedback mechanism.

AUTOMATIC DETECTOR TEST SYSTEM



Slide 1

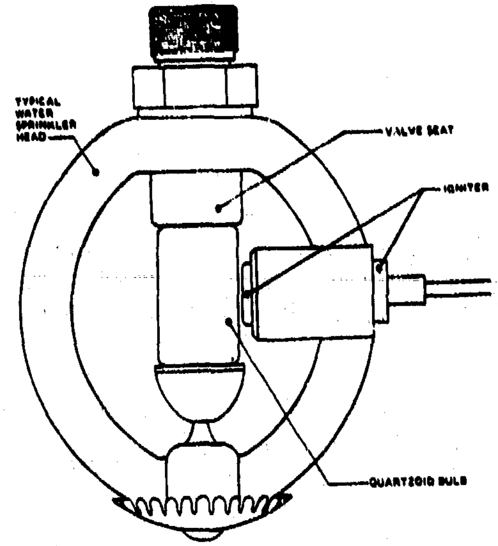
The detector will respond to ultraviolet radiation emitted from flame, and flame is a common characteristic of munitions fires. However, the radiation must reach the sensor before response can be achieved, and contamination of the optical surfaces of the detector enclosure could interfere with normal operation. This problem is largely overcome by the Det-Tronics Automatic Optical Integrity design, which was described during the DDES Seminar in 1976. The concept utilizes an optical feedback loop, controlled by an ultraviolet signal through the quartz window of the detector enclosure. The physical arrangement is shown on slide 2. Note that the UV sensor and UV source are mounted inside the same enclosure, but are optically isolated from each other. The only path of transmission for a UV signal from the source to the detector is out through the window, where it is reflected from the exterior ring mirror and back into the enclosure through the center portion of the window.



Slide 2

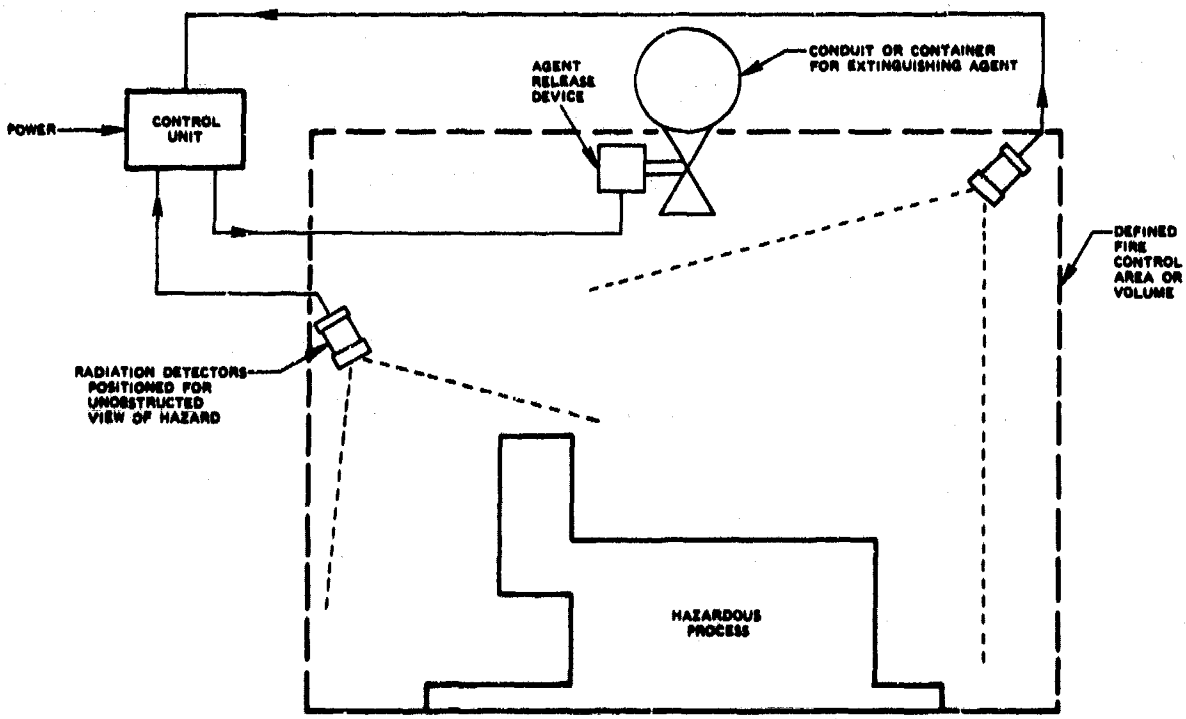
The output circuits from the UV detection system must be connected to equipment capable of the desired response to a fire signal. In petroleum applications, such as offshore platforms, an immediate alarm is generally desired, followed by release of fire suppressant and/or the bypass or shut-down of machinery. With fires involving munitions materials, however, the fire develops more rapidly, and no time delay can be utilized before release of the fire suppressant. Because of its high heat capacity and inherent penetrating characteristics, water is the primary agent used for suppression, and the time it takes to release the water from its container is an important element in total system response time. The Bofors tests employed a unique sprinkler head that minimizes total water delivery time, and the design of this device is illustrated on slide 3. Note that the water valve is held in place by a quartzoid bulb filled with a high expansion fluid that will shatter the bulb at a predetermined temperature.

This is identical to a variety of commercially available heads, and affords a temperature-responsive back-up to the automatic release device. This automatic release is achieved by an electrical signal from the UV detection system, which ignites a small explosive device attached to the bulb support frame. In the Bofors design, a special arrangement insures that the bulb will be shattered, and appropriate measures for patent protection have been taken by Bofors. You will note during the film sequence that the time from actuation until water begins to flow from the sprinkler head is less than one millisecond.



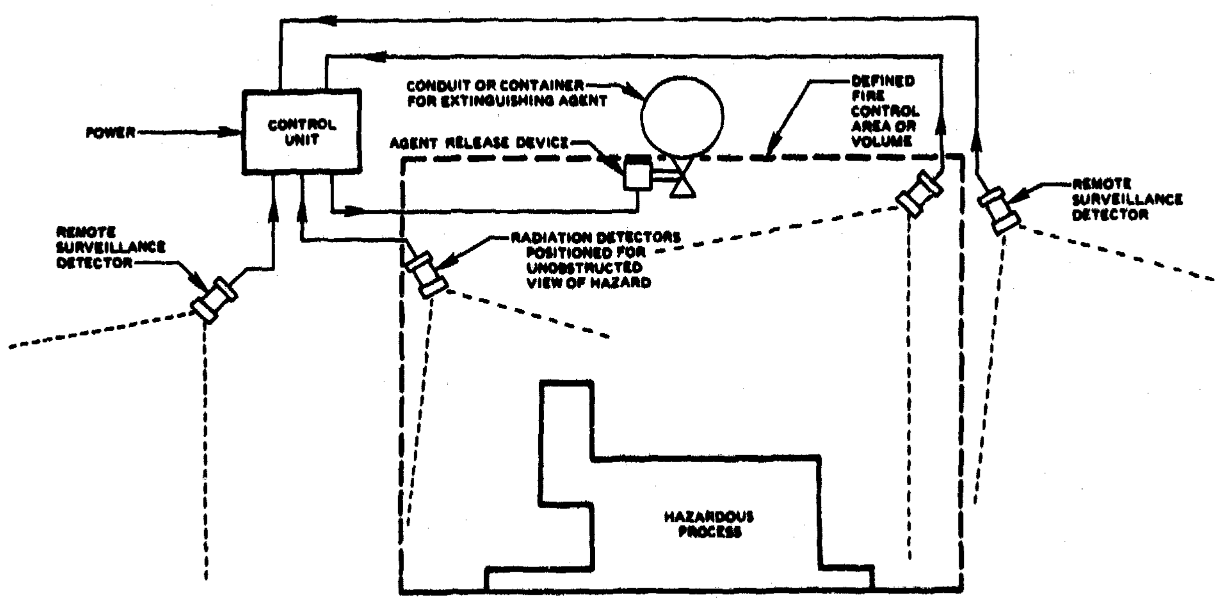
Slide 3

A closed-loop fire protection system utilizing the various components described above is illustrated on slide 4. In addition to the detectors and extinguishing equipment, the major elements of such a system include (a) the hazard to be protected, (b) the proper positioning of the detectors for an unrestricted view of the hazard, (c) the proper positioning of nozzles so that the hazard will be completely covered upon release of the extinguishing agent, (d) a means of conducting the agent to the nozzle, or of storing it for immediate release, (e) an uninterruptible electric supply for powering the detectors and explosive actuators, and (f) a definition of the controlled fire zone.

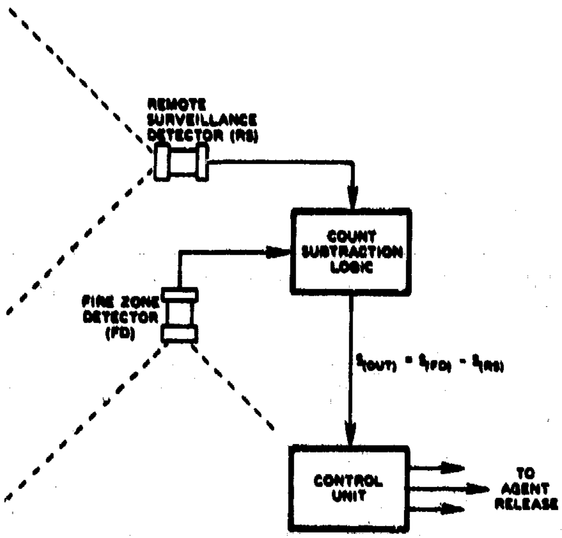


Slide 4

A careful definition of the protected area has an importance that must not be overlooked. First of all, it identifies exactly what will fall within the range of the extinguishing agent, and what will not. It follows that the area or volume beyond which the suppressant control extends is of no concern to the equipment in the controlled fire area. Furthermore, radiation signals arriving from these remote locations are of absolutely no value in terms of the performance of the fire protection system, and could have a detrimental effect on its performance. In keeping with the truth inherent in these observations, Det-Tronics has developed a "Remote Surveillance" system, as already mentioned, and are currently making applications on gasoline transport loading racks, offshore oil platforms, and aircraft hangars. The concept is applicable anywhere that radiation signals from outside the controlled fire area may interfere with the performance of the fire protection system within the controlled fire area. Slide 5 illustrates the concept in terms of hardware. Note that remote surveillance detectors have been added to the previously defined installation, and that these devices are positioned in such a manner that they can receive radiation arriving from outside the controlled fire area, but are unable to respond to radiation from within the controlled fire area. The output of these remote surveillance detectors is then fed into a microprocessor, which is part of the signal processing electronics, and this signal is then subtracted from the signal being generated by the remote source in the detectors performing the fire protection function. If a fire would occur within the fire zone, those detectors would have a greater output than the remote suveillance detectors, and a fire signal would be entered, completely independent of remote radiation. The concept is shown diagrammatically on slide 6.



Slide 5



Slide 6

Several points of information are needed before we view the Bofors film sequence. First of all, there were three different materials used in the test series, two of which were types of Black Powder, and the third a nitrocellulose powder. The material identified as NOA97 has a burn rate of 1600 millimeters (63 inches) per second; the material NOA91 has a burn rate of 2500 millimeters (98 inches) per second; the material NC1066 has a burn rate of only 13 millimeters (0.5 inches) per second. Some of the tests were performed with mixtures of these three powders. The physical arrangement of the test site is such that the detectors are positioned 10 feet from the center of the bench, the water nozzles are 3 feet from the powder under test, and the water flow per nozzle is 20 gallons/minute at 75 PSI. The sprinkler valve actuator requires 300 milliamperes, and the opening time of the valve is less than 1 millisecond. You will note that mannequins have been placed in typical work positions at the test bench, and their hands have been covered with gauze so that the danger of burns to personnel could be evaluated. An indication of the fast response of the system lies in the fact that the gauze covered hands of the mannequins showed no signs of burns during the test series.

We wish to thank the Bofors company for the use of their film, and we also wish to express our appreciation to the organizers of this 19th Explosives Safety Seminar for the opportunity to present this material and to describe the advances in detection and extinguishing technology that have occurred since the 1978 session.

CUTTER FIRES

George F. Becker
Naval Ordnance Station
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BACKGROUND:

For several years NOS has been cutting Terrier Casting Powder on small arms powder cutters manufactured by McKiernan Terry Corp. During this time period a number of fires occurred. This paper is a review of some of the things tried to eliminate cutter fires and the measure of success.

DISCUSSION:

At NOS three (3) different formulations of Terrier casting powder (ABL 705, 917 & 1362) are manufactured. These powders when cut contain approximately 33% ether and ethyl alcohol in a ratio of 2/3 ether to 1/3 alcohol. The powder strands are .050" diameter and are cut to .050" length. Figures 1-6 show the cutter in operation and the various component parts such as powder receiving can, conductive velostat plastic skirt, powder chute, sprinkler head and alcohol misticcator. In Figure 6, the cutter safety shield is shown partially removed. These shields were installed after a cutter fire, with vapor explosion inside, broke the cutter door and threw fragments across the bay. Although this incident was with high energy powder - shields were installed on all cutters. As the powder is being cut, an alcohol mist is sprayed onto the rotating cutter blades just before the blade approaches the cutter block. The alcohol cools and lubricates the cutter blades.

In Table I is listed the cutter fire frequency, location and powder type from 1969 to present. It should be noted that all cutter fires but one have occurred while processing ABL 917 and ABL 1362 casting powders. The explanation for this is as follows:

a. ABL 917 if discharged from mixer in a soft condition "gum-up" the cutter block and blades. This build-up of propellant on the blades or block then becomes subjected to excess friction and ignites.

b. The coarse aluminum used in ABL 1362 plays havoc with the cutter blocks and blades. The wear on blades is greater and elongation of the cutter block holes is more evident. This means blade adjustments, blade changes, cutter block filing have to be done more frequently and operators and machinist have to be more alert to these potential problems.

c. Badly worn cutter blades and cutter blocks can be causes of cutter fires. Adjustments become more difficult.

d. Crevices in cutter block doors can "hide" casting powder granules. When the door is closed, these granules sometimes fall between the door and support stud or blade cover; this causes the cutter to be out of adjustment.

A summary of Table I is listed below:

POWDER TYPE	NO. OF CUTTER FIRES
ABL 1362	20
ABL 917	14
ABL 705	1

Cutter Location	Bldg. 706 No. 1	Bldg. 706 No. 2	Bldg. 707 No. 1	Bldg. 707 No. 2
No. of Fires	11	8	5	9

Table I also shows that after the 1 August 1972 cutter fire in Bldg. 706 No. 2, there were only four (4) cutter fires in eight (8) years. This we believe is due to some changes and improvements made after this fire.

It is a known fact that any fire needs a source of ignition, a fuel to burn and oxygen to support combustion. In the past cutter fire investigation effort concentrated on the elimination of the source of ignition. Several avenues were investigated to not only eliminate the ignition source but also to lower the ether concentration in and around the cutter receiving can. This could prevent propagation perhaps, even if there were some ignition of individual powder granules.

The following changes were made after the 1 August 1972, cutter fire:

a. Screen wire vents were installed in the powder chutes to dissipate ether fumes. What effect this has made cannot be measured.

b. Installed three (3) ground wires in powder chute so they dangle in the powder stream. What effect this has made cannot be measured.

c. In one cutter, the conductive plastic skirt was replaced with 325 mesh copper wire cloth. This did not work very well because the wire cloth was to stiff and did not hang into the powder can properly. It was replaced with conductive plastic.

d. Two (2) cutters were equipped with air ionizers using 3M Co. polonium 210 as source of alpha particles. The air ionizers were used for approximately six (6) months. Their use was stopped since the operators complained that the noise interferred with sound of the cutter operation, which is used to determine how the cutter functions. The use of ionized air is believed to be helpful in eliminating static.

e. The air flow into the exhaust louvers was measured in the cutter rooms in Bldgs. 706 and 707. It was found that the air flow varied considerably (see Table II). On further investigation it was found that the exhaust blowers had a clogged screen that restricted the air flow. After cleaning the screen and making adjustments in the air intake louvers, the air flow was increased by factor of 2 to 4 times.

TABLE II

BLDG.	CUTTER BAY	AIR VELOCITY BEFORE CHANGES	AIR VELOCITY AFTER CHANGES	AIR FLOW BEFORE CHANGES	AIR FLOW AFTER CHANGES
706	#1	8 ft/sec	14 ft/sec	450 cu ft/min	798 cu ft/min
706	#2	4.7 ft/sec	17 ft/sec	264 cu ft/min	957 cu ft/min
707	#1	8 ft/sec	16 ft/sec	350 cu ft/min	900 cu ft/min
707	#2	5 ft/sec	21 ft/sec	282 cu ft/min	1180 cu ft/min

f. The location of the cutter machine, exhaust louver and outside doors varied considerably (see Figure 7). Consequently there is considerable variation in the ventilation in the four (4) cutter rooms at different times of the year depending on whether one or two outside doors are open.

There are other factors that will have some effect on ventilation and static. These are as follows:

Outside temperature
Wind velocity
Relative humidity
Whether heater blower is on
In the summer a 24" pedestal fan is used
Length of duct from blower to air intake
Number of bends in ventilation duct

g. Electrostatic potential at the cutters has been measured from time to time. Measurements have been made at the discharge chute, in the free space between the conductive plastic skirt and the aluminum powder receiving can and just above the bottom of the can where the powder first begins to accumulate. At the discharge chute opening, potentials of 200 to 450 volts have been measured. These potentials are sometimes maintained for the duration of cutting although in many tests potentials decrease rapidly to 100-200 volts indicating discharge paths have been established.

In the free space within and beneath the skirt, measured potentials quickly peaked about 200 volts and decreased in a few seconds to about 50 volts. Near the bottom of the powder collection can, potentials peak at aoubt 50 volts and decrease in a few seconds to very low values (0-10 volts), as a layer of cut powder accumulates. This decrease with distance maybe partly attributable to dispersion of the powder causing less impingement on the voltmeter probe screen as well as discharging.

Attempts to detect a potential on the surface of freshly cut powder immediately after completion of cutting generally have shown insignificant accumulation. The fires that have occurred, frequently are in the vapor space above the collected powder with little evidence of burned powder found in subsequent investigation. It is thought that electrostatic discharge thru the flammable vapor space is responsible for some of the fires.

SUMMARY

a. Since 1 August 1972 (8 years ago) there has been only four (4) cutter fires. These fires were in 706 #1 and 707 #1 cutter bays, which have the greatest distance from powder receiving can to exhaust louver, and have two (2) doors, which when open would channel the air away from the powder can. Therefore, it is believed the increase in exhaust air flow and the shorter distance between the cutter receiving cans exhaust louver helped in reducing the number of cutter fires.

b. It is concluded that the exhaust system for both buildings should be redesigned and separate blower installed for each bay with the exhaust intake close to the powder can.

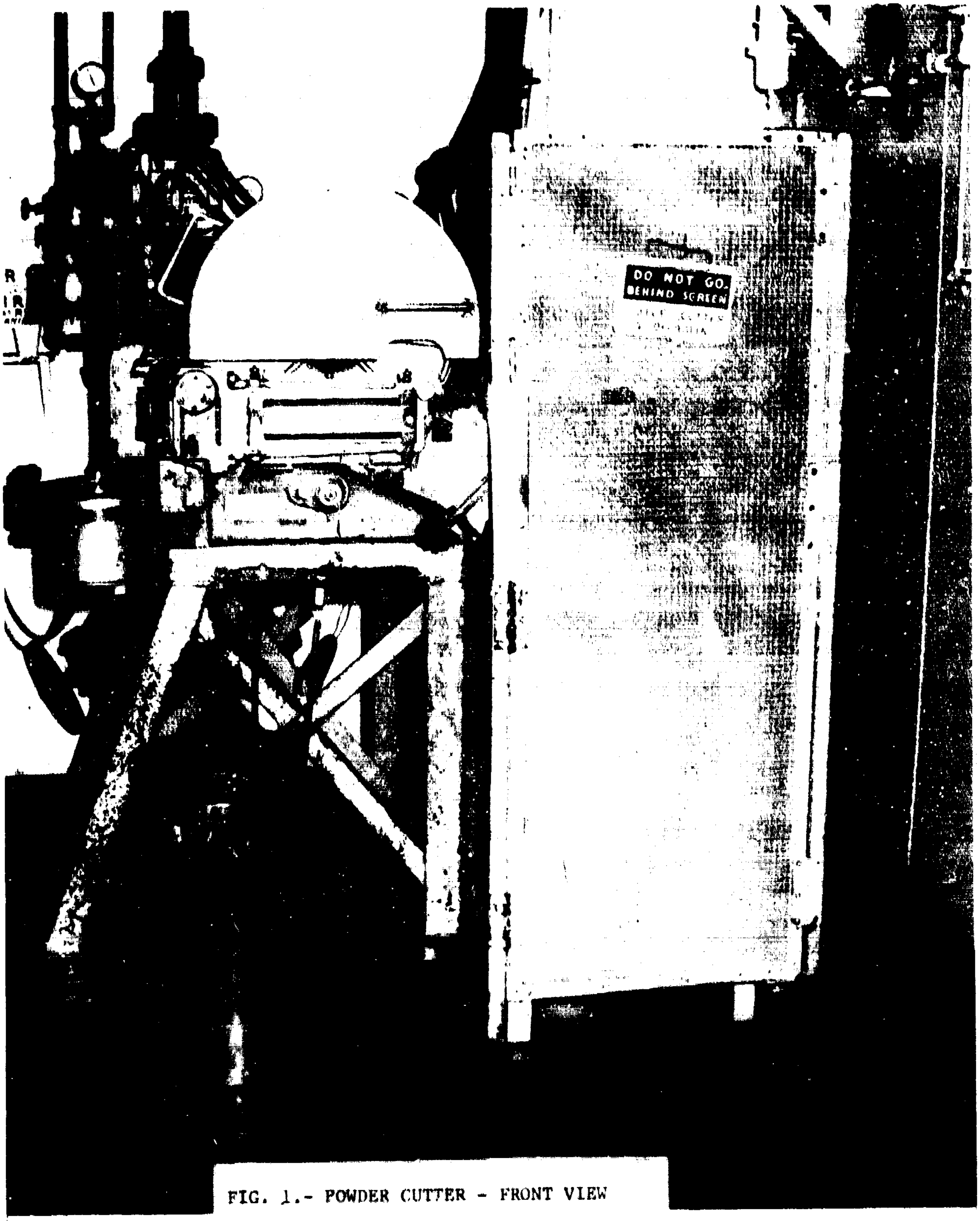


FIG. 1.- POWDER CUTTER - FRONT VIEW

TABLE I

FREQUENCY OF CUTTER FIRES

DATE	TIME	PRODUCT	CUTTER LOCATION
3-3-69	1830	ABL-1362	706 #2
3-9-69	0340	ABL-1362	707 #2
6-17-69	0930	ABL-1362	706 #2
6-22-69	2245	ABL-917	707 #2
6-23-69	0700	ABL-917	706 #1
6-24-69	1445	ABL-917	706 #1
7-14-69	1745	ABL-1362	707 #1
7-15-69	1815	ABL-1362	706 #1
7-28-69	2130	ABL-1362	706 #2
10-1-69	0620	ABL-917	706 #1
11-21-69	1645	ABL-1362	1035 #3
12-3-69	2230	ABL-1362	1035 #3
8-18-70	1330	ABL-917	707 #2
8-19-70	1300	ABL-917	707 #1
9-18-70	1430	ABL-917	707 #2
10-9-70	1630	ABL-917	707 #1
10-13-70	1730	ABL-917	707 #1
11-5-70	040	ABL-1362	706 #1
12-23-70	1745	ABL-1362	706 #1
12-28-70	1655	ABL-1362	706 #1
3-9-71	0725	ABL-705	706 #2
4-5-71	0541	ABL-1362	707 #2
4-15-71	0825	ABL-1362	707 #2
4-25-71	0924	ABL-1362	707 #2
4-27-71	2115	ABL-1362	706 #1
5-8-71	0158	ABL-1362	707 #2
12-15-71	0140	ABL-1362	706 #1
12-19-72	2134	ABL-917	706 #2
6-1-72	1252	ABL-917	706 #2
6-15-72	0520	ABL-917	706 #2
8-1-72	1610	ABL-917	706 #2
9-16-74	2130	ABL-1362	707 #1
9-18-76	2227	ABL-917	707 #1
3-9-79	1447	ABL-1362	706 #1
8-30-79	0818	ABL-1362	706 #1

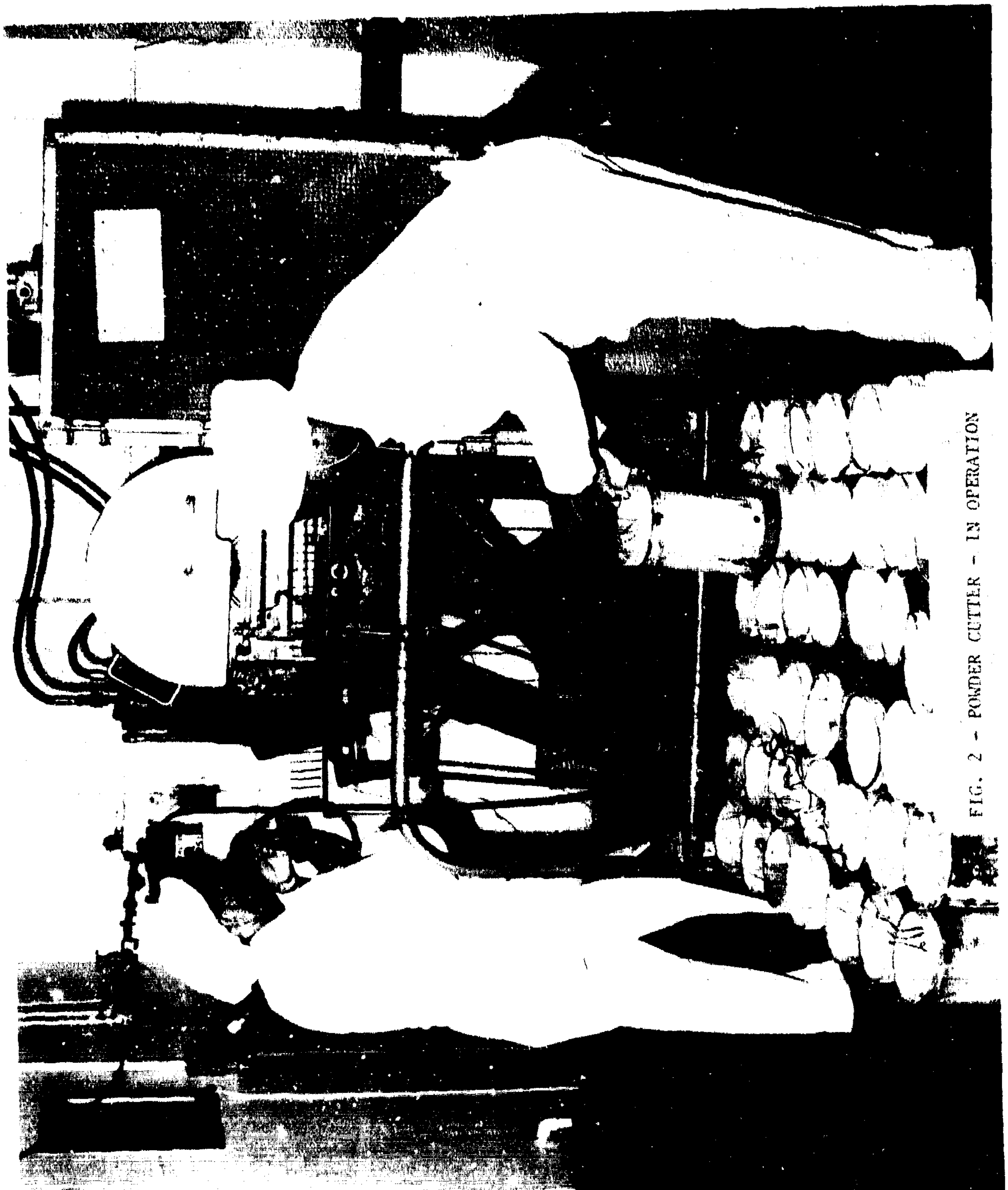


FIG. 2 - POWDER CUTTER - IN OPERATION

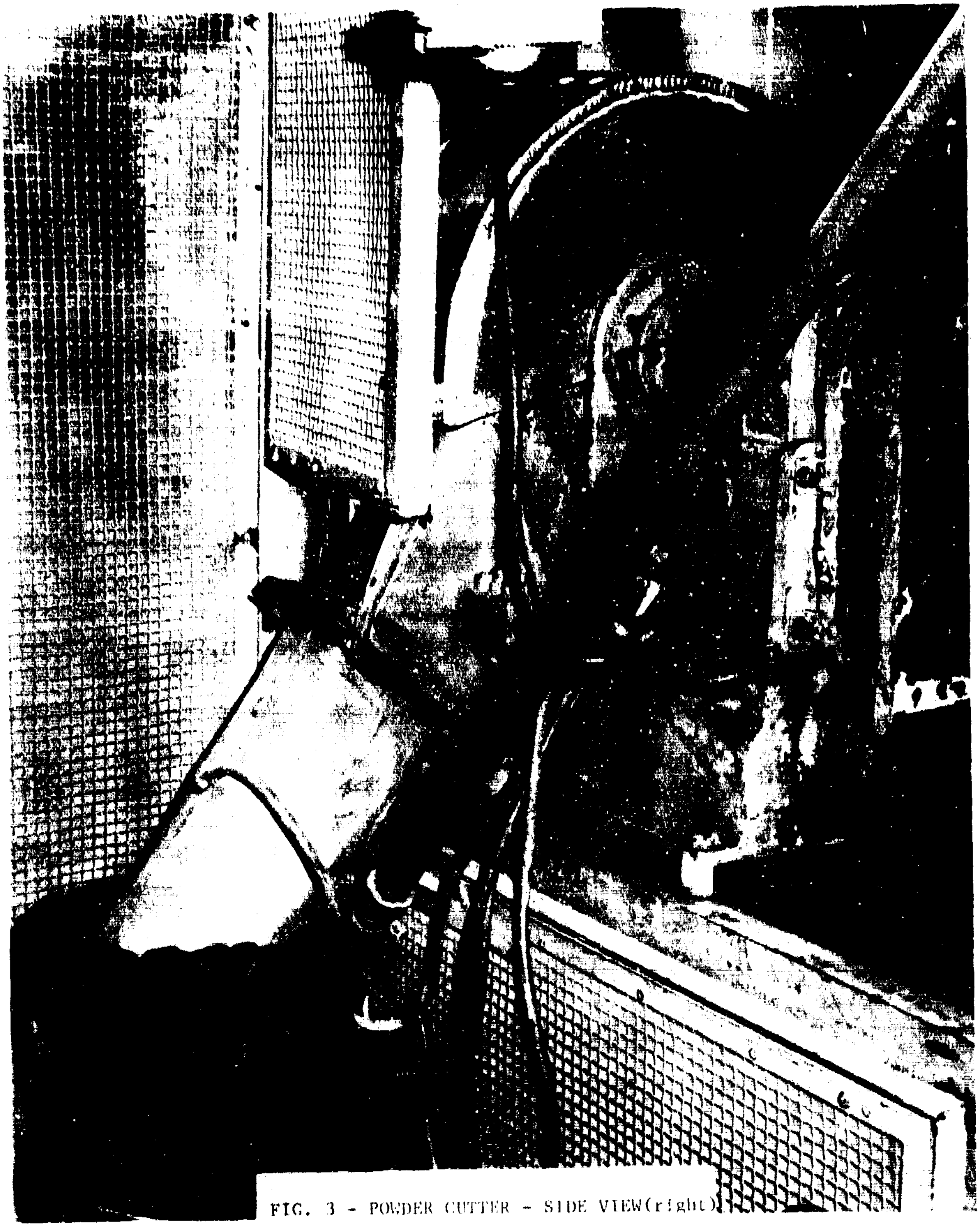


FIG. 3 - POWDER CUTTER - SIDE VIEW(right)

FIG. 4 - DISCHARGE CHUTE & GROUND WIRE

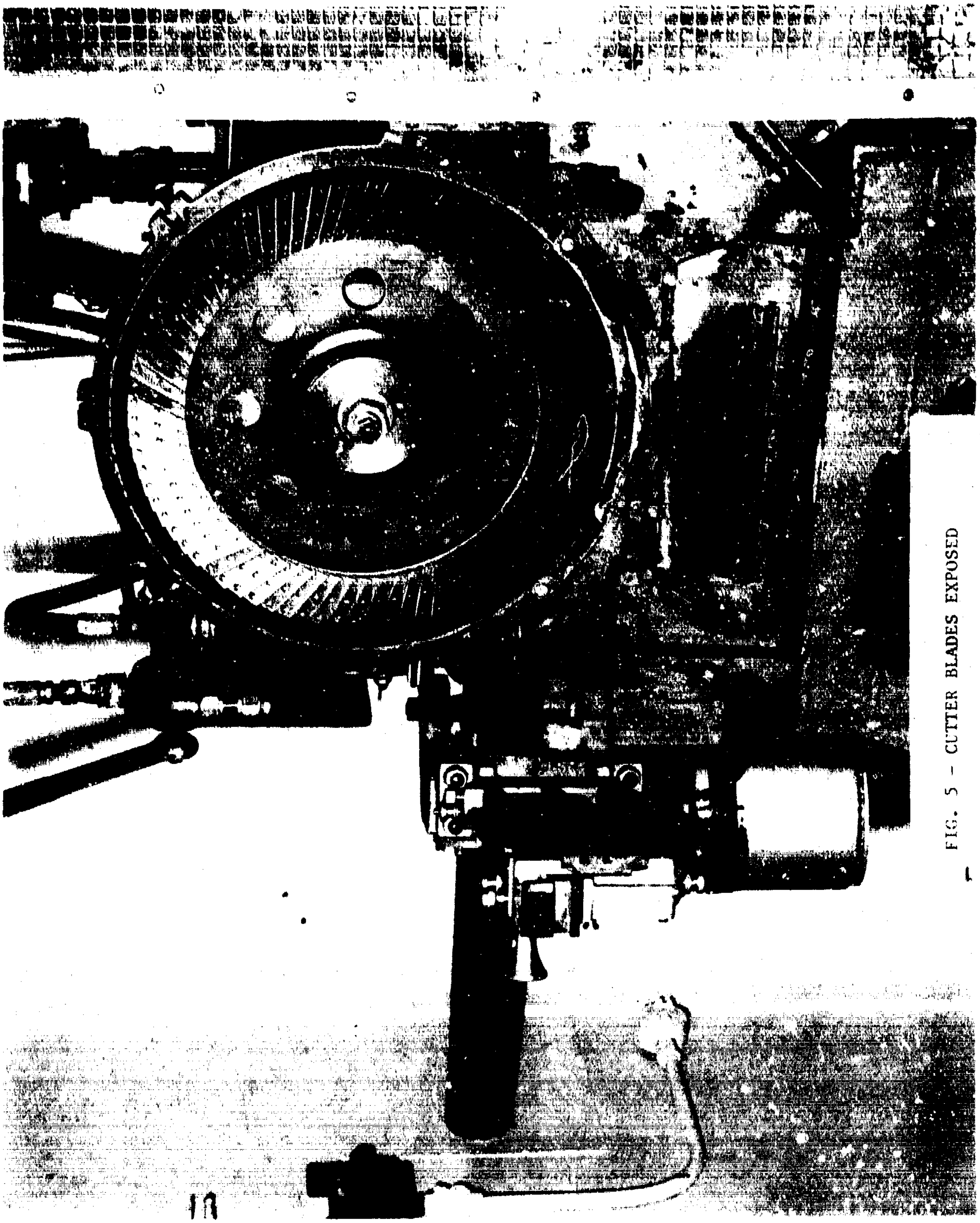


FIG. 5 - CUTTER BLADES EXPOSED

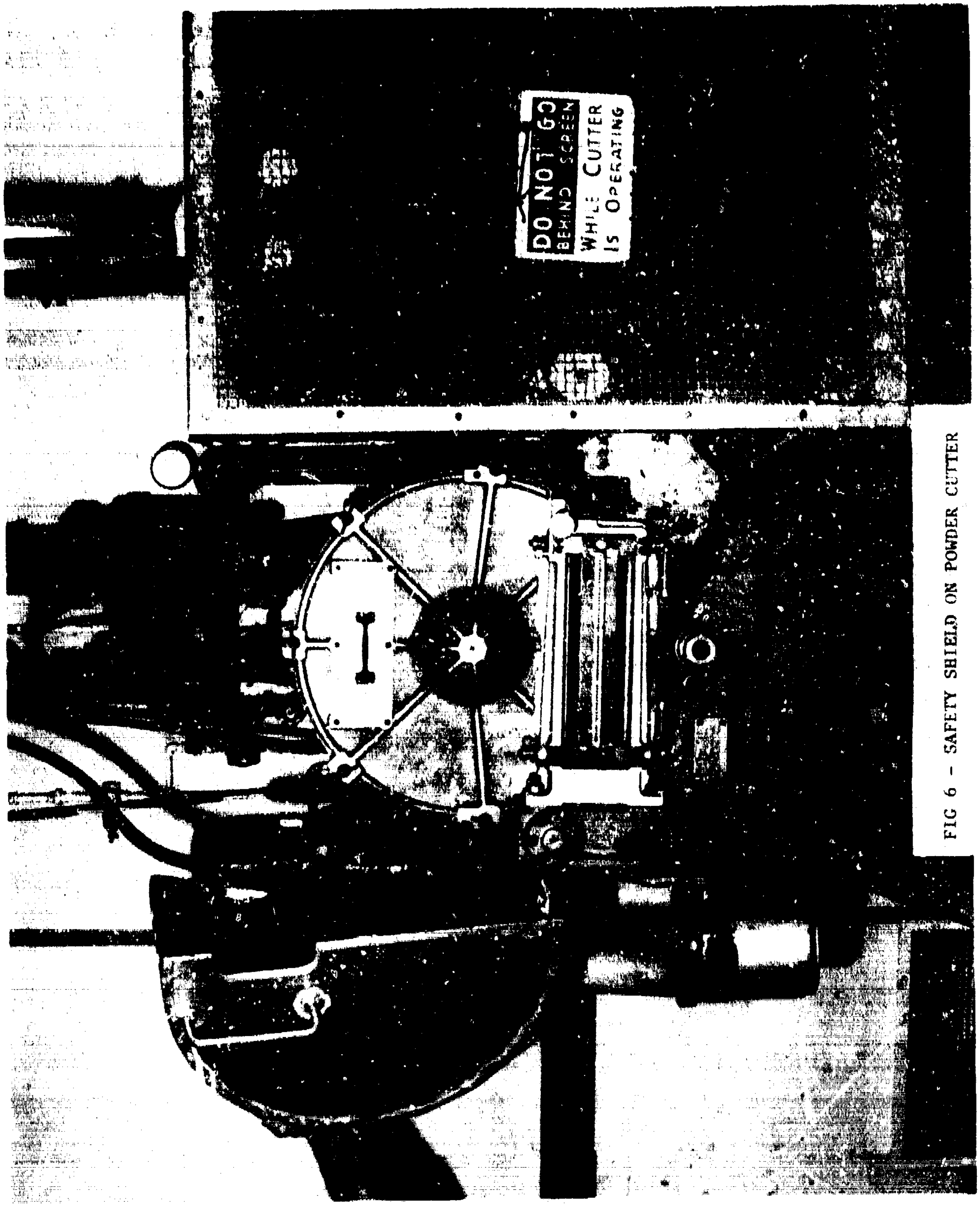
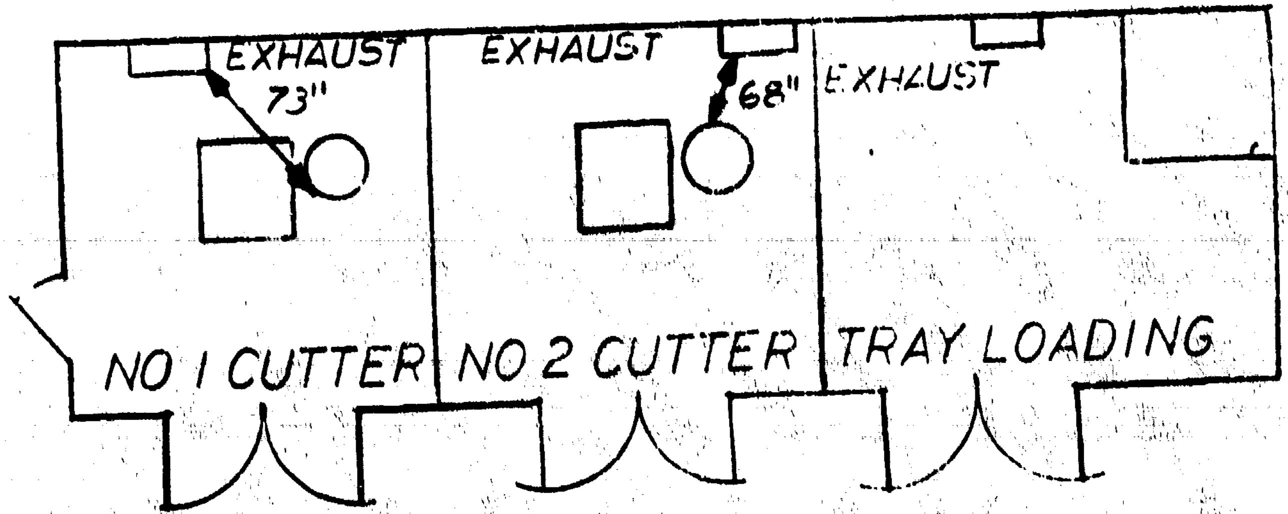
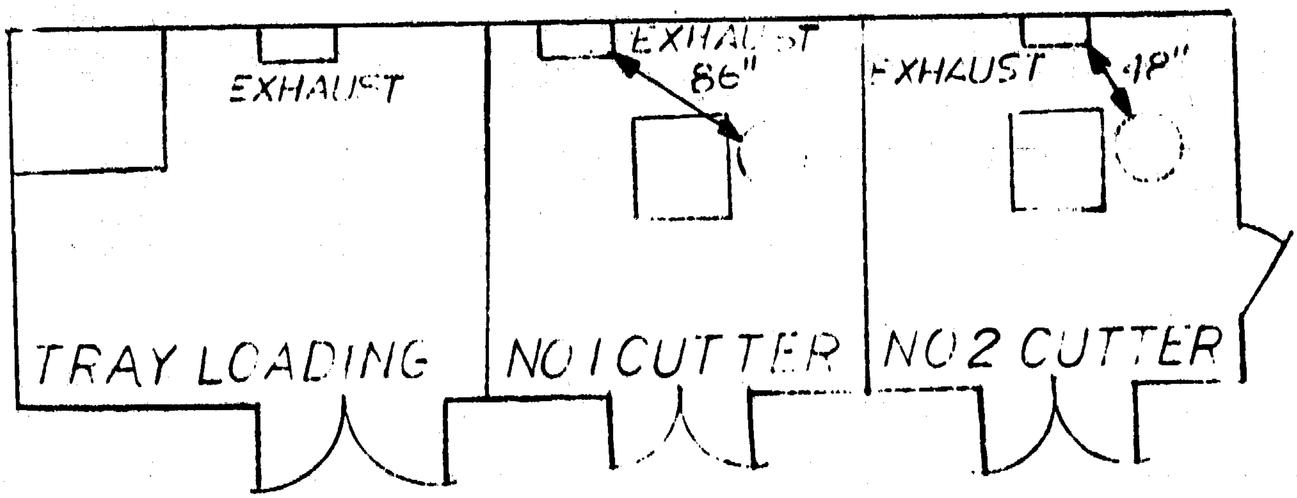


FIG 6 - SAFETY SHIELD ON POWDER CUTTER



BUILDING 706



BUILDING 707

FIGURE 7
LOCATION OF AIR EXHAUST
AND DOORS

MASON & HANGER-SILAS MASON CO., INC.
IOWA ARMY AMMUNITION PLANT
MIDDLETOWN, IOWA

MULTI-TOOLED IOWA DETONATOR LOADER

PRESENTED BY: JOE E. SHANNAN, SAFETY MANAGER

MULTI-TOOLED IOWA DETONATOR LOADER

Soviet Bloc troops, tanks and artillery greatly outnumber those of the United States and its Allies.

We have countered this threat through increased fire power via the family of improved conventional munitions. With these munitions everything from instant mine fields to the saturation of advancing armor are available to our defending Army.

Requirements for detonators have risen astronomically with the advent of the family of improved conventional munitions.

The Jones Loader was the original automated detonator loading machine, utilizing a rotary design with an indexing dial. It is still in use today.

The Iowa Detonator Loader, which was designed and developed by Mason & Hanger-Silas Mason Co., Inc., in 1969, has become the standard of the industry, with over 60 in use throughout the nation and in several foreign countries by government plants and private industry.

The Iowa Loader is similar to the Jones Loader in that it also uses a rotary design and an indexing dial, but there is an important difference: The Iowa Loader uses a reciprocating center shaft, or column, to supply the necessary force for the consolidation and crimping operations. By using this reciprocating center column, balancing problems are eliminated and maintenance accessibility greatly improved.

Another significant advantage of the Iowa Loader is its flexibility. The Iowa Loader utilizes a modular concept whereby each tooling station mounts in a 15° pie shape on the chassis. Also, each pie shape on the upper and lower tool mounting plates is drilled and tapped identically so that any tooling module can be mounted at any of the 24 station positions. This modular concept allows easy adaptation to the various detonators.

In an attempt to save facilities and equipment procurement funds, the Project Manager's Office for Production Base Modernization and Expansion conceived and funded a project for the development of a multiple-tooled Iowa Loader. The objective of this project was to design and fabricate a machine that could produce two, three or more detonators per machine stroke and thereby increase the production capacity of the existing facilities and equipment.

A study was made to show the potential cost reductions associated with the Multi-Tooled Iowa Loader. This study adjusted for the expected decreased availability due to increased complexity and the projected increased equipment and tooling costs. It also adjusted for several factors peculiar to detonator production such as tooling replacement due to in-process detonations.

Design layouts were prepared for various tooling configurations capable of accommodating from two to five tooling sets.

Also, preliminary station concepts for consolidation, powder metering, and automatic traying were prepared. Quad tooling was selected.

The prototype multi-tooled loader was tooled to produce the M55 Detonator, which is by far the highest quantity production item in the Army's arsenal. The M55 is a three-increment, stab-type detonator measuring .146" in diameter x .140" tall.

The production of the M55 involves individually metering, consolidating, and monitoring the consolidated height of three explosive powders - NOL 130, Lead Azide, and RDX. Also, a .003" thick aluminum closure disc is blanked and placed on top of the RDX. The detonator is then crimped and sealed with lacquer. The loading machine performs all of the above operations with the exception of lacquering.

At Station One, the M55 detonator cups are automatically placed in the dial tooling. A vibratory parts feeder delivers the cups open end up into four separate tracks.

This vibratory track unit guides the moving cups into a vacuum-assisted holding device. Four punches connected to the machine center column push the cups out of the holding device into the sleeve of the waiting station tooling in the indexing dial. Before placing the first powder charge in the cup, a powder guide or funnel is placed on top of the cup.

At Station Two, an air-operated powder guide transfer mechanism moves out to the four powder guides setting on rest pins on the indexing dial. The powder guides are picked up, moved into position over the dial tooling and set down on top of the cups. Sensors monitor mechanism position to assure correct sequence with the machine cycle.

A safety tested operational shield, located at Stations Four and Five, houses the powder scooping mechanism which will place the first powder charge, NOL 130, in the cup. Inside the shield this double scooper mechanism deposits powder into four cups located beneath the shield.

The scooper mechanism is driven from the machine's cam shaft to provide positive synchronization and a smooth motion. At Station Seven, a pressure ram consolidates the first powder charge. This ram is identical to four others on the machine which are used to either consolidate powder or crimp closed the completed detonator.

The mechanical operation is obtained through a toggle linkage connected to the machine reciprocating center column.. The actual consolidating force is controlled hydraulically. The NOL 130 is consolidated to approximately 85,000 psi.

During the dwell portion of the center column cycle, with the consolidation punches at the bottom of their stroke, a height measurement is electronically recorded and displayed on the control panel. Should the powder heights deviate from a predetermined range, a reject light will be illuminated on the control panel and the computer memory system will retain this reject information. When the finished detonators are removed from the machine, this information will be used to automatically separate the rejected and acceptable product.

A load cell registers the force applied by each punch. This is converted to a pressure equivalent and displayed. There is one readout for each consolidation station for height and pressure but the reading for any position may be obtained by turning the selector switch to the position desired.

The average reading of the last ten detonators produced at any one position may be displayed by pushing the average button. The number displayed is in tenths of thousands of an inch; that is, the average height of the last ten finished detonators at this position is - .9 thousandths.

At Station Nine, the second powder charge, lead azide, is dispensed. An operator places a cup of powder in the powder handler and remotely fills the dispenser hopper. Inside the operational shield a specially designed air-operated, ball-type dispensing unit provides a quantity of powder into each of the four detonator cups. The timing sequence is controlled by the machine's programmable limit switch which provides a machine-timing interface to the process controller for many of the machine's operations.

The quantity of powder dispensed into any of the four detonator cups is controlled by the adjusting rods mounted beneath the door. Consolidation of the lead azide charge occurs next at Station 11.

The dial indicators are used to assist in setup and as a mechanical verification of the electronic powder height monitoring system. Monitoring and display of powder height and pressure occurs as mentioned.

At the following station a small aspirating device, similar to other units on the machine, vacuums loose powder from the dial tooling and powder guide rest pins. Since the third powder charge, RDX, will be in a pellet form there is no longer a need for a powder guide. The mechanism returns the powder guides to their original position. It is similar to the unit used earlier at Station Two.

Once the powder guides have been placed in position on the rest pins, proximity sensors check for presence of each powder guide. A malfunction of the mechanism will cause an emergency stop with an appropriate indication at the control panel.

Station 14 is an air operated pellet feeder which places the third and last powder charge in the detonator cup. This station normally operates with eight tubes, loading pellets from every other one. When these four tubes are empty, the tube rack shifts to allow the slide fingers to load from the full tubes. Empty tubes can be removed and replaced at a later, more convenient time.

Four punches connected to the machine's center column push the pellet out of the slide fingers and into the detonator cup. Proximity sensors check the mechanism position to assure correct sequence with respect to machine operation. Should there be a malfunction, machine shutdown and proper indication at the control panel would occur.

The pellet charge is consolidated at Station 15. As with other consolidating stations, a check and display of powder height and pressure is made. Another cleaning operation occurs at Station 16. A foil disc is now placed on top of the consolidated RDX.

Four strips of foil are fed through individual blanking dies. The discs are then punched out and placed in the detonator. All motion is mechanical, derived from the center column action.

The reciprocating center column is the heart of the Iowa Loader and most of the stations derive their motion from it. It is cam-controlled and air cylinder assisted. For the multi-tooled loader, this cam was redesigned to achieve greatly reduced consolidation punch velocity as it enters the powder guide and compresses the explosive. This resulted in increased and more consistent firing output levels than previously experienced on the single-tooled machine.

At Station 19, a pressure ram identical to the other rams, but without height or pressure monitoring instruments, forms the top edge of the cup to a 45° angle. To complete the crimp forming operation, a pressure ram at Station 21 presses the top of the cup flat to form a seal

with the foil disc. The finished height of the detonator is electronically measured and displayed. The completed detonator is now ready to be removed from the machine.

When the dial index stops, a mechanical push rod pushes the detonators out of the station sleeve and into rubber chucks in the bottom of an aluminum transfer block. As the chuck block moves toward the transport tray, reject detonators are ejected into a chute leading to the reject barricade.

Accepted detonators are placed in the transport trays. A five-position cam, ratcheted after each loader index, provides an accurate stop which positions the transfer block over each row in the transport tray. Completion of five rows necessitates indexing the tray forward to start a new five-row fill sequence.

A completed tray contains 40 detonators with two rows left blank. The completed trays are then conveyed to an inspector. The detonators are manually inspected for various dimensional and visual defects. They are then manually transferred to the non-propagating pack.

As mentioned, the consolidating and crimping forces are controlled hydraulically. They are monitored and controlled from the console. Any of the individual pressures may be easily and quickly adjusted from here.

The electronic control system for the multi-tooled loader is two-fold. It is designed to be both a Supervisor System and a Data Acquisition System. The supervisory functions include the normal machine start and stop operations as well as fault detection during machine operation. The analog devices used on the consolidation stations provide numerical data to the process controlled so a decision can be made concerning the quality of each detonator as it is produced.

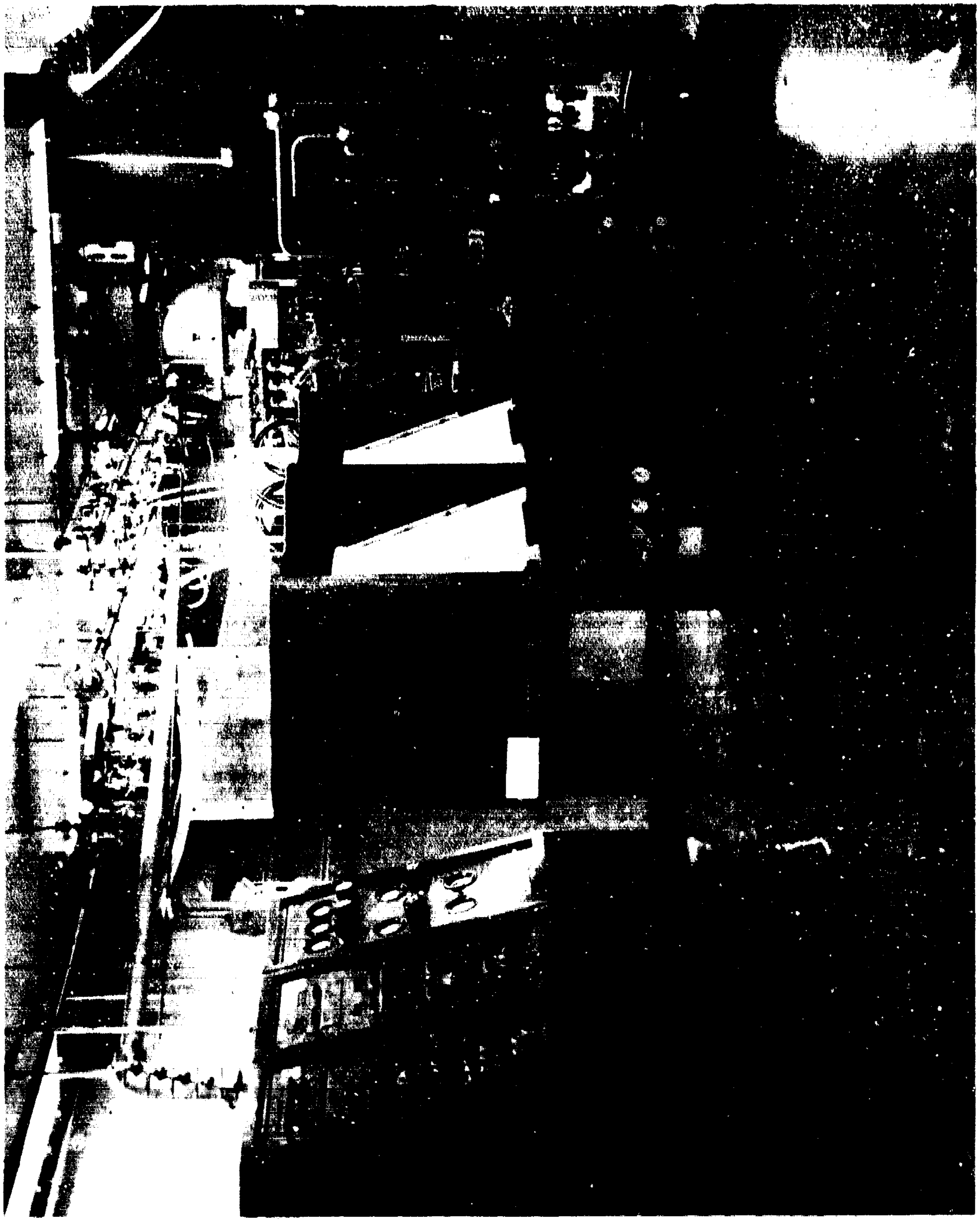
In addition to controlling and monitoring many of the machine's stations, the microprocessor constantly monitors all utility levels - air pressure, hydraulic pressure, vacuum level, purge pressure and electrical power - and if any deviate from their normal range the machine stops and the reason is indicated.

Thumb-wheel switches on the console allow the foreman or operator to communicate with the microprocessor. By dialing the appropriate number, which is listed on a reference sheet, operational data can be obtained. These thumb-wheel switches are also input devices. If, for example, the RDX consolidation reject parameters require changing from + or -3 thousandths to +2 -4 thousandths, it is done easily.

At projected peacetime rates, the Multi-Tooled Iowa Loader will produce detonators at a 33% savings compared with existing equipment. Much more importantly, the development of this machine has resulted in a significant increase in capacity per square foot of factory space. This could result in a reduction of new building costs of up to $20 million.

The strength of Mason & Hanger designed Iowa Detonator Loader is its flexibility to produce the wide variety of detonators required in relatively small quantities during peacetime, while maintaining reasonable efficiency at mobilization rates.

The multi-tooled design capitalizes on the versatility and proven technology of existing machines while providing significantly reduced operating and capital outlays.



PROGRESS REPORT ON EXPLOSIVES MACHINING STUDY

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August 1980

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PROGRESS REPORT ON EXPLOSIVES MACHINING STUDY

I. INTRODUCTION

The machining of explosives is required to produce and/or demilitarize the majority of Navy ordnance. To reduce risks, OP 5[1] provides the constraints regulating machining operations. Of prime importance are those concerning the machining variables, i.e., cutting speed, depth of cut, and tool feed rate. The cutting speed limit is considered too conservative by some; however, a fairly recent explosion while core sampling a cast plastic-bonded explosive has raised the caution flag. Considerable machining experience has been compiled on explosives with low melting point ingredients, such as TNT and wax, that impede achieving excessive temperatures in those explosives. Today's plastic-bonded explosives are designed for high temperature use, and therefore do not contain those "built-in safety valves".

This study, sponsored by the Logistics Safety Office of the Naval Sea Systems Command, is to quantify, if possible, the hazardous effects of the machining variables.

Initiation of an explosive is a thermal phenonema where input energy, regardless of its form (impact, shock, etc.), is converted to heat, increasing internal energy until an activation level is reached - an exothermic chemical reaction occurs providing heat for additional reactions to occur, continuing the cycle, until a "runaway" condition exists.

Therefore, if the effect of a machining variable is to raise explosive temperature, then it has increased the possibility for initiation to occur. Consequently, it was decided that an investigation of the heat producing effects of the machining variables, as manifested by explosive temperature increases, would provide the most beneficial insight as to their hazard-producing potentials.

Normally, maximum temperature occurs in the relatively small mass of the explosive chip due to rupture along its shear plane and subsequent sliding across the cutter face. Since it is difficult to measure temperature at that point without disturbing normal chip flow, plus the desirability for interchangeable cutter use, a thermocouple-instrumented spacer that supports the cutter insert (Figure 1) was used as an indirect measure of chip temperature.

Even though thermocouple temperature is a function of several variables, i.e., chip temperature, area of the chip-cutter interface, and heat conduction path through the cutter, it should serve as a relative measure of heat produced in the chips of various materials being machined.

[1]NAVSEA OP 5, Ammunition and Explosives Ashore (Safety Regulations for Handling, Storing, Production, Renovation and Shipping)

II. PROCEDURE

A lathe turning operation with a single pointed cutter, no coolant, and easy chip removal was selected as the optimum for isolating the cutting variables' effects. Two types of tungsten carbide cutter inserts were used to demonstrate the effects of positive and negative back rake cutters, while providing uniformity in cutter shape and surface characteristics. A thermocouple installed in the cutter seating spacer of the tool holder assured consistency in monitoring the same discreet area of the underside of the clamped-in cutter (Figure 1).

The initial effort was to evaluate the effects of cutting speed, depth of cut, tool feed rate and cutter configuration on the thermocouple temperature for various inert materials. Ranges of the machining variables were selected to suit the eventual explosive study, and were:

50 - 300 surface feet per minute cutting speed (CS).

.005 - .096 inch depth of cut (Dp).

.002 - .020 inch per revolution feed (Fd).

Preliminary trials of the test setup on inert materials disclosed two very fortuitous aspects of the thermocouple location; first, it was very sensitive to changes in the machining variables, and secondly, for any set of machining conditions a substantially constant or stabilized temperature would be maintained. The temperature rise, Δt (stabilized minus ambient), provided the measurable effect of the machining variables.

A statistical method, the two-level factorial design, provided the means for determining the effect of cutting speed, depth of cut, and feed rate for each cutter configuration in the minimum number of experiments. Analysis of those results led to a procedure for developing a mathematical relationship between the variables and Δt for each of the materials studied.

The inert study provided a convenient means of verifying procedures and establishing a reference base of data for materials of widely differing physical properties.

To date, machining experiments have been completed for five explosives - TNT, HBX-1, PBXN-3, PBXN-104, and PBXN-105. Equations, relating thermocouple temperature to the machining variables for each type cutter, have been derived. All of the relationships are presented in Table I.

To better illustrate the comparative effects of those equations, the maximum explosive machining limits permitted by OP 5, i.e., 210 surface feet per minute cutting speed, 0.188 inch depth of cut, 0.035 inch per revolution feed, were used to calculate Δt's for each material. These are shown in Table II.

The temperature equations established for the metals are intended to provide a general basis for comparison of materials. The machinability of metals can be drastically affected by composition, heat treatment, work hardening, etc., and is a very complex subject, not to be explored here.

Although the temperature of the explosive chip is the primary concern, comparison of the thermocouple temperatures achieved by machining various materials at the same conditions should provide a measure of the relative heat-generating, and therefore hazard-potential, characteristics.

Lacking a means of directly measuring the chip-cutter interface temperature, a method for roughly estimating it was developed. By using 93 degrees Celsius (°C) and 316°C temperature-indicating crayons, and deducing that interface contact area is related inversely to chip temperature, the following equations were derived:

$$\text{(1)} \qquad \text{For metals, } t_c = \frac{\Delta t}{2\ Dp + .01}$$

$$\text{(2)} \qquad \text{For non-metals, } t_c = \frac{1.75\ \Delta t + 22}{1.75\ Dp + 1}$$

Insertion of the standard machining conditions and calculated Δt's of Table II in Eqs. (1) and (2) permitted the calculation of estimated chip temperatures also listed in Table II.

An example of the method for determining experimental machining conditions and subsequent derivation of the Δt equations are shown in Table III and Figure 2. The ranges of each variable, x_1, x_2, and x_3, were 100 to 300 surface feet per minute cutting speed, 0.016 to 0.048 inch depth of cut, and 0.005 to 0.020 inch per revolution feed, respectively. The plus or minus signs for those variables in the matrix determine whether the high or low limit value of the range will be used for each experiment. Δt's, provided by the temperature traces, are recorded in Table III.

The effect of each variable and their interaction is found by taking the arithmetic sum for each column (assigning the plus or minus value to each test number Δt). Dividing each columnar total by the number of test runs, eight in this instance, provides a measure of the effect of each variable and their interactions (only positive values have significance). Assuming the total effect of the variables accounts for the range of Δt values produced, proportionate values of that range are calculated for each. These values are then divided by the range of their respective variables to get a per unit of measure change. Inserting these values in

$$\Delta t = a \times CS + b \times Dp + c \times Fd + d \times CS \times Dp \ldots + K \quad (3)$$

and solving for each test condition provides the means for determining the constant, K.

III. DISCUSSION OF RESULTS

The thermocouple-instrumented spacer in the tool holder has proven to be a very satisfactory means of monitoring the heat produced in the cutter-chip interface, since it is surprisingly sensitive to machining conditions, does not interfere with chip travel, and facilitates the replacement of cutter inserts.

The temperature rise equations for the various materials are easily verified due to the small number of trials required by the two-level factorial designed experimental method.

The Δt values, at standard conditions, shown in Table II, appear representative of the expected relative energies required to machine those materials, thus lending credence to this method of evaluating them. There are substantial differences in the heat-production characteristics of the explosives while being machined at the same cutting speed, depth of cut and feed rate. This is shown by the range of thermocouple Δt's, from a low of 10°C for TNT, to three times that for PBXN-104. Estimated chip temperatures would be approximately 30°C and 63°C, respectively.

The relative effects of each of the variables, and their interplay, on Δt remained fairly constant throughout the gamut of materials investigated. Depth of cut exerted the strongest effect, followed by cutting speed and feed rate, with their ratios of magnitude being roughly 2.2:1.9:1.0, respectively.

The "worst case" explosive, PBXN-104, results in a Δt of 32°C when machined with a positive rake cutter at the OP 5 machining limits, as shown in Table II. If the depth of cut were increased from 0.188 inch to 0.25 inch, Δt would increase to 41°C, and calculated chip temperature to 65°C.

It must be remembered, however, that although useful for assessing the relative hazards of machining various materials, a Δt of the implanted thermocouple may be attributable to a high temperature explosive chip making very little surface contact with the cutter, or a lower temperature chip with considerable surface contact. Explosive chip temperature should be the basis for assessing specific hazardous machining conditions. Determining chip temperature through analysis of a very complex heat transfer situation would be very difficult, so empirical solutions from a few "known" conditions were developed. Hopefully, it may be refined and verified by future experiments.

IV. OBSERVATIONS

This study, to date, has achieved the following:

- The machining variables' effects have been related to explosive temperature, an optimum indicator of its chemical stability or hazard potential.

- The simplicity of the instrumentation and the proficiency of the statistically designed test method have enabled the accumulation of a considerable amount of meaningful data with relative ease in a short period of time.

- Expression of the variables' temperature effects in equation form has negated the need for describing them in cumbersome, less effective, alternate methods such as families of graphs, etc.

- Comparison of the Δt's achieved by various explosives under the same machining conditions provides a measure of the relative hazard potentials of those materials.

V. CONCLUSIONS

The explosive machining limits must allow for other than ideal conditions. Instances where foreign materials, broken tools, and inadvertent cutting of warhead hardware have occurred in the past without incident while machining the older, "safer" explosives; they can be expected to recur. Whether the new plastic-bonded explosives will survive that type abuse has not been established as yet due to the relatively small quantities of cased PBX's machined to date.

This study provides evidence that an appreciably more hostile environment is produced while machining PBXN-104 as compared to TNT. The Δt equations provide a means for calculating increased machining variables' limits for TNT to raise it to a comparable risk level. The relative insensitivity to initiation of TNT would further support such a move, if desired.

Lack of experience at the increased hazard level, plus the confusion resulting from tailored machining limits, would make such a move inadvisable at this time.

The mechanics of explosive initiation is not an exact science. Avoiding accidental initiations requires good judgement based upon experience, sensitivity testing, and a knowledge of the hazard potential of the environment to which explosives will be exposed. Many additional explosive compositions are planned for study in an attempt to better define the environmental hazards they will be subjected to while being machined.

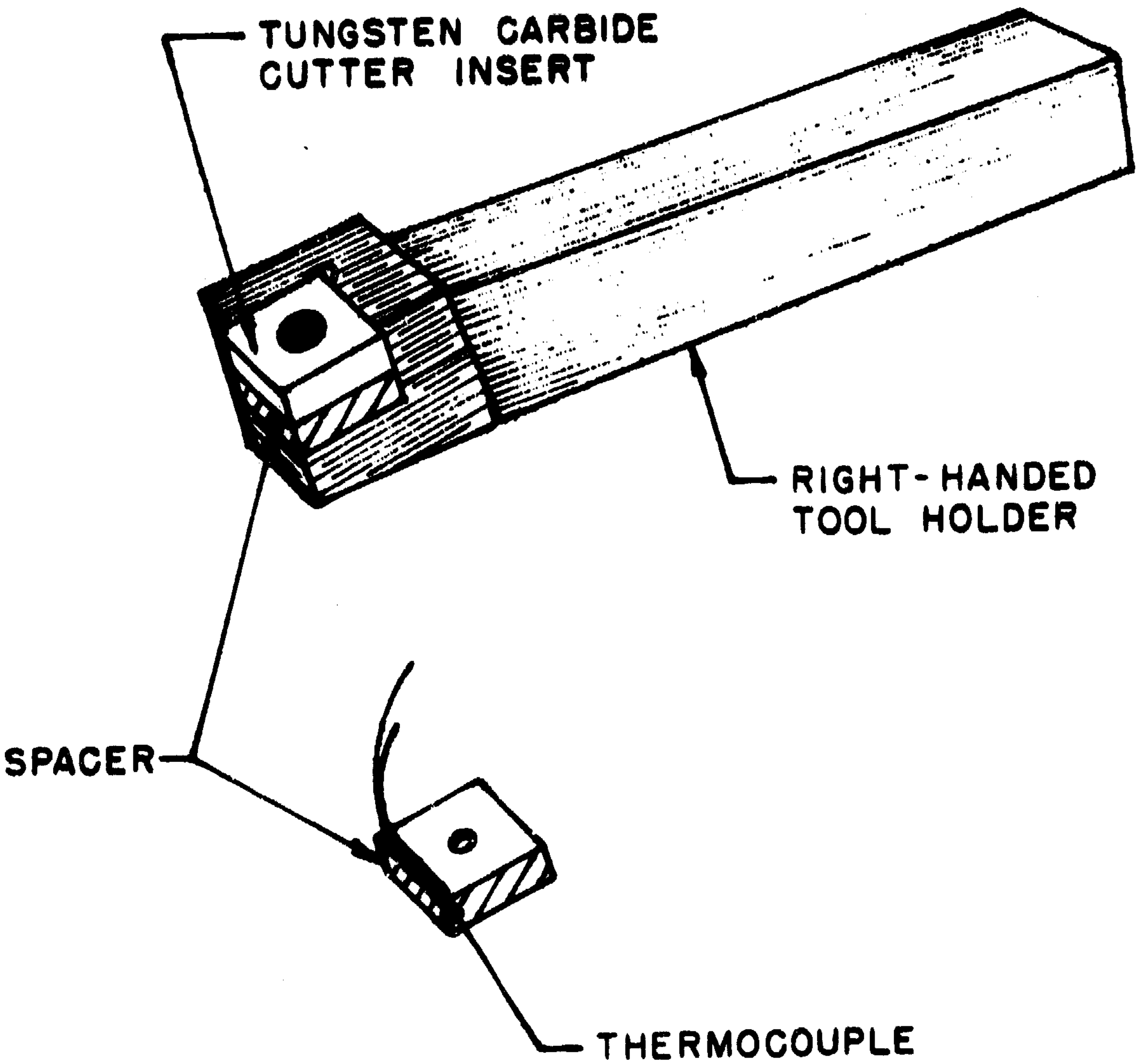

FIGURE 1
CUTTER ASSEMBLY AND
TEMPERATURE SENSOR LOCATION

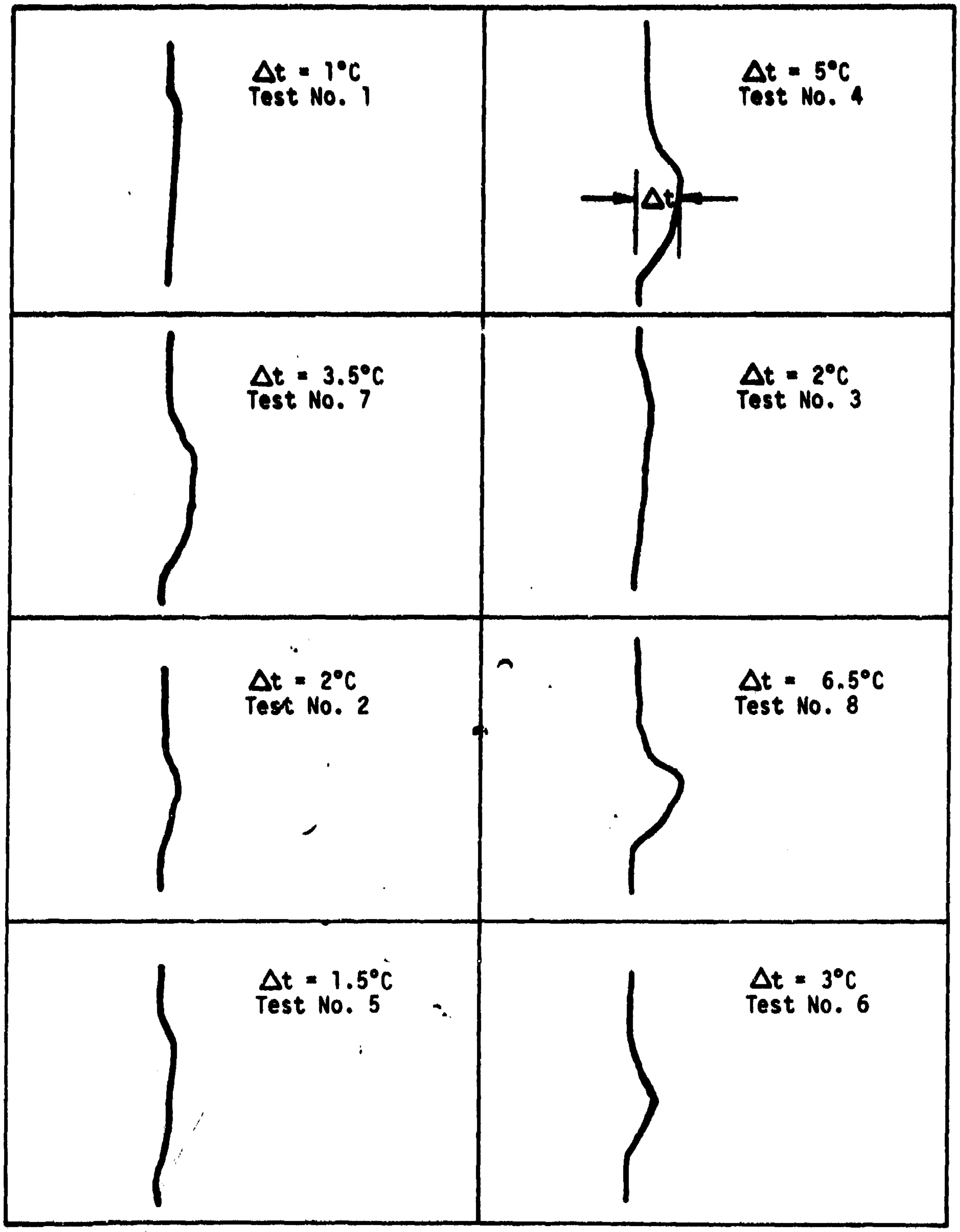

FIGURE 2. LATHE TURNING EXPERIMENT - TEMPERATURE TRACES FOR HBX-1

TABLE I. EQUATION COEFFICIENTS

Material	Back rake	a	b	c	d	e	f	g	K
Inert:									
Airdi Steel	Pos	0.20	1625	4310	2	...	40,000	...	-23
	Neg	0.48	1420	6520	...	4	34,800	...	-35
1020 Steel	Pos	0.13	1415	3535	2	4	...	...	-18
	Neg	0.20	1855	5120	2	...	...	...	-20
Beryllium Copper	Pos	0.08	1175	2450	...	...	...	...	...
	Neg	0.08	2170	3500	...	...	36,800	...	-2
6061 Aluminum	Pos	0.08	540	2727	0.3	...	14,200	...	-15
	Neg	0.11	616	3913	...	...	12,858	...	-16
Velostat	Pos	0.06	250	300	...	...	5,780	22	...
	Neg	0.04	220	520	0.1	...	2,200	...	-3
PVC	Pos	0.07	390	670	0.2	0.7	...	...	-8
	Neg	0.06	34	825	...	1.2	...	23	-6
PBXN-104 Simulant	Pos	0.06	310	580	0.1	0.4	...	...	-8
	Neg	0.03	425	630	0.1	...	1,000	...	-20
Teflon	Pos	0.03	95	440	0.1	...	975	...	-3
	Neg	0.02	75	525	0.1	...	1,750	...	-2
Filler E	Pos	0.01	40	20	0.03	...	...	...	...
	Neg	0.01	56	30	0.02	...	...	...	...
Explosive:									
PBXN-104	Pos	0.02	125	194	0.05	...	...	...	-4
	Neg	0.02	129	258	0.04	...	430	...	-7
PBXN-3	Pos	0.02	102	74	...	0.1	...	...	-1
	Neg	0.02	146	62	0.05	...	...	...	-2
HBX-1	Pos	0.01	88	106	...	...	...	...	-2
	Neg	0.01	63	63	0.06	...	...	...	-2
PBXN-105	Pos	0.02	41	95	...	...	...	...	-2
	Neg	0.02	69	134	0.09	...	...	...	-3
TNT	Pos	0.01	36	60	0.03	...	...	...	-2
	Neg	0.01	36	60	0.03	...	...	...	-2

$$\Delta t = \underline{a \times CS} + \underline{b \times Dp} + \underline{c \times Fd} + \underline{d \times CS \times Dp} + \underline{e \times CS \times Fd} + \underline{f \times Dp \times Fd} + \underline{g \times CS \times Dp \times Fd} + \underline{K}$$

TABLE II. COMPARATIVE Δt AND CHIP TEMPERATURE FOR MATERIALS MACHINED AT OP 5 MAXIMUM LIMITS*

Material	Pos rake		Neg rake	
	Δt (°C)	Chip temp (°C)	Δt (°C)	Chip temp (°C)
Inert:				
Airdi Steel	818	1718	819	1721
1020 Steel	507	1065	629	1321
Beryllium Copper	323	679	787	1653
6061 Aluminum	304	639	344	723
Velostat	139	200	83	126
PVC	117	171	82	125
PBXN-104 Simulant	90	135	99	147
Teflon	47	78	50	82
Filler E	12	32	15	36
Explosive:				
PBXN-104	32	59	35	63
PBXN-3	25	49	34	61
HBX-1	20	43	17	39
PBXN-105	13	34	22	46
TNT	10	30	10	30

Chip temperature, for metals, $t_c = \dfrac{\Delta t}{2\ Dp + .01}$

Chip temperature, for non-metals, $t_c = \dfrac{1.75\ \Delta t + 22}{1.75\ Dp + 1}$

*OP 5 maximum limits:

210 surface feet per minute
0.188 inch depth of cut
0.035 inch per revolution feed

TABLE III. LATHE TURNING EXPERIMENT

MATERIAL: HBX-1

DATE OF EXPERIMENT: 2/7/80

Test No.	Cutting speed (ft/min)		Depth of cut (in.)		Dia of cut (in.)	Rotational speed (rpm)		Feed (in./rev)	Ambient temp (°C)	Stable temp (°C)	Actual Δt (°C)	Calculated Δt (°C)
	Target	Actual	Target	Actual		Target	Actual					
5	100	93	.016	.016	6.336	60	56	.020	18.5	20	1.5	1.3
2	300	280	.016	.016	6.336	180	169	.005	18.5	20.5	2	2.4
7	100	92	.048	.048	6.304	60	56	.020	18.5	22	3.5	3.5
1	100	93	.016	.016	6.336	60	56	.005	18.5	19.5	1	.3
6	300	280	.016	.016	6.336	180	169	.020	18.5	21.5	3	3.3
8	300	279	.048	.048	6.304	181	169	.020	18.5	25	6.5	5.9
3	100	92	.048	.048	6.304	60	56	.005	18.5	20.5	2	2.5
4	300	279	.048	.048	6.304	181	169	.005	18.5	23.5	5	4.9

CUTTER RAKE: NEG

$\Delta t = .01\ CS + 63\ Dp + 63\ Fd + .06\ CS \times Dp - 2$

Δt RANGE: 5.5

Test No.	CS x_1	Dp x_2	Fd x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	Δt
1	-	-	-	+	+	+	-	1
2	+	-	-	-	-	+	+	2
3	-	+	-	-	+	-	+	2
4	+	+	-	+	-	-	-	5
5	-	-	+	+	-	-	+	1.5
6	+	-	+	-	+	-	-	3
7	-	+	+	-	-	+	-	3.5
8	+	+	+	+	+	+	+	6.5

EFFECTS | COEFF

$x_1 = 1.06 \div 3.25 \times 5.5 \div (200) = .01$

$x_2 = 1.19 \div 3.25 \times 5.5 \div (.032) = 63$

$x_3 = 0.56 \div 3.25 \times 5.5 \div (.015) = 63$

$x_1x_2 = 0.44 \div 3.25 \times 5.5 \div (12.8) = .06$

$x_1x_3 = 0.06$

$x_2x_3 = 0.19$

$x_1x_2x_3 =$ -

TOTAL: 3.25

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